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JOURNAL

of the

AMERICAN WELDING SOCIETY

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Volume 7 **SEPTEMBER, 1928** **Number 9**

TABLE OF CONTENTS

Society and Related Activities

Page

Program Fall Meeting 3
Annual Year Book 6
Registration 6
Technical Discussion 6
Section Activities 7
Employment Service Bulletin 7

Technical Papers, Items and Reports

Standard Line of D. C. Machines Fabricated by Metal Arc Welding, by Messrs. R. S. Marthens, C. C. Brinton and F. T. Hague 8
Maximum Allowable Working Fibre Stresses in Welded Structures, by S. W. Miller 21
Production Welding in the All-Steel Automobile Body Industry, by J. W. Meadowcroft 28
Running a Successful Job Welding Plant, by J: S. Oechsle 41
Arc Welding, A Study by H. Dustin and Translation by F. T. Llewellyn .. 51
Erection of Buildings by Welding, by J. F. Lincoln 72
An Interesting Thesis on Structural Arc Welds, by M. Shimkin 84
Present Status of Welding Steel Buildings by Electricity, by F. P. McKibben 97
Some Structural Aspects of Welds in Specimen of Fire Box Steel Tested at Normal and Elevated Temperatures, by a Subcommittee 114
Elevated Temperature Tests of Welds, by a Subcommittee 128
Current Welding Literature 143

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PROGRAM

1928 FALL MEETING

of the

AMERICAN WELDING SOCIETY

to be held in

PHILADELPHIA, PA., October 8, 9, 10, 11 and 12, 1928

BELLEVUE-STRATFORD HOTEL

Exposition at Commercial Museum All sessions start promptly as scheduled

IMPORTANT NOTICE

Members and their guests are requested to register, as admission to Commercial Museum and some of the social events will be by badge only.

MONDAY, OCTOBER 8, 1928

Morning

Registration—Registration facilities will be provided for members and guests at the Bellevue-Stratford Hotel each morning, commencing Monday, October 8th, from 10:00 A.M. to 12:00 M., and at Commercial Museum each afternoon, commencing Monday from 1:00 P.M. to 5:00 P.M. A registration fee of $1.00 will be charged members and their male guests.

Afternoon

Meeting of Board of Directors, American Welding Society, 2:30 P.M., Bellevue-Stratford Hotel, Assembly Room.

TUESDAY, OCTOBER 9, 1928

Morning

Business Session

10:00 A.M., Bellevue-Stratford Hotel.

This will be more in the nature of a few introductory remarks by President Llewellyn and transaction of any formal business or introduction of local celebrities.

TUESDAY, OCTOBER 9, 1928

Morning

Technical Session

10:30 A.M., Bellevue-Stratford Hotel, F. T. Llewellyn, President, Presiding.

Welding in Heating, Ventilating and Plumbing Industry, by R. A. Jack, Domestic Engineering.

Oxy-Acetylene Cutting in the Structural Field, by D. E. Roberts, Linde Air Products Company.

Afternoon

Technical Session

2:30 P.M., Commercial Museum, Lecture Room, F. M. Farmer, Past President, Presiding.

Welds at Elevated Temperatures, by Professor C. Moser, Leland Stanford University.

Welding in the Automobile Industry, by J. W. Meadowcroft, Asst. Works Manager, Edward G. Budd Manufacturing Co.

Evening

GRAND BALL

9:30 P.M., Grand Ball, Benjamin Franklin Hotel, Ballroom. Admission by Ticket Only.

WEDNESDAY, OCTOBER 10, 1928

Morning

Technical Session

10:00 A.M., Bellevue-Stratford Hotel, R. D. Thomas, Chairman, Philadelphia Section, Presiding.

Running a Successful Job Welding Plant, by J. S. Oechsle, President, Metalweld, Inc.

Formula for Computing Design Stresses for Pressure Vessels, S. W. Miller, Union Carbide and Carbon Research Laboratories.

Afternoon

Inspection Trip

1:30 P.M.

An inspection trip has been arranged to the Naval Aircraft Factory, League Island Navy Yard, which is the largest Government plant for the manufacture of Hydroplanes. Arrangements have been made for the party to leave the Bellevue-Stratford Hotel at 1:30 P.M. by bus. The return trip will terminate at the Commercial Museum in order to provide an opportunity for those who so desire it to visit the Exhibit.

Arrangements for special trips may be made at the time of registration to the plants of the E. G. Budd Manufacturing Company and the welded building of the General Electric Company at West Philadelphia.

THURSDAY, OCTOBER 11, 1928

Morning

Joint Pressure Vessel Committee

10:00 A.M., Bellevue-Stratford Hotel, E. H. Ewertz, Chairman, Presiding.

Afternoon

Technical Session

2:30 P.M., Commercial Museum, Assembly Room. A. G. Oehler, Past President, Presiding.

Design of Welded Structures, by F. P. McKibben, Consulting Engineer, General Electric Co.

Erecting a Building by Welding, by J. F. Lincoln, Lincoln Electric Co.

Evening

Annual Banquet and Dance

6:30 P.M., Bellevue-Stratford Hotel, Annual Banquet and Dance.

FRIDAY, OCTOBER 12, 1928

Morning

Technical Session

10:00 A.M., Bellevue-Stratford Hotel, J. H. Deppeler, Past President, Presiding

Testing Joints for Aircraft Structures Prepared Under Procedure Specifications, by H. L. Whittemore, Bureau of Standards, and H. H. Moss, Linde Air Products Company.

Design of Machinery Parts by Use of Welding of Steel Shapes, by Messrs. Hague, Marthens and Brinton, Westinghouse Electric & Mfg. Co.

Afternoon

American Bureau of Welding

2:30 P.M., Bellevue-Stratford Hotel, C. A. Adams, Director, Presiding. Meeting of American Bureau of Welding

Evening

Structural Steel Welding

8:00 P.M., Bellevue-Stratford Hotel, J. H. Edwards, Chairman, Presiding. Meeting of Structural Steel Welding Committee.

ENTERTAINMENT FOR LADIES

Monday

October 8, 1928

Luncheon at Benjamin Franklin Hotel, Betsy Ross Room, 12:30 P.M., followed by automobile ride. Admission by ticket only.

Tuesday

October 9, 1928

Bridge party, Benjamin Franklin Hotel, Betsy Ross Room, or shopping tour, 2:00 P.M.

Wednesday

October 10, 1928

Automobile Tour to Valley Forge, 1:30 P.M. Admission by ticket only.

Thursday

October 11, 1928

Sightseeing tour at 2:00 P.M., followed by Tea at the Benjamin Franklin Hotel (Tea at 4:00 P.M. in the Betsy Ross Room). Admission by ticket only.

Annual Year Book

Members of the American Welding Society are respectfully requested to study carefully the new Year Book of the American Welding Society recently distributed to all members, and in particular, to become familiar with the work of the technical committees and the research department of the Society, known as the American Bureau of Welding. This Society is actively engaged in standardization and code work including such items as nomenclature, definitions and symbols, code for pressure piping, code for welding in building construction, pressure vessel code and research work on fundamentals of welding, welded rail joints, pressure vessels, structural steel and welding wire. This Year Book is prepared annually at considerable expense to the Society in order to furnish a review of the activities and accomplishments of the Society, as well as a directory of its membership.

Additional copies of the Year Book will be furnished on request to be used in soliciting new members. An application blank is given on the last two pages of the Year Book for the convenience of prospective members.

Annual Dinner Dance

Tickets for the Annual Dinner Dance of the American Welding Society at the Fall Meeting may be purchased at the time of registration at $5.00 per ticket. The dinner committee has made every effort to insure the success of the dinner and an excellent menu, music and entertainment will be provided.

Registration

Registration facilities will be provided for members and guests at the Bellevue Stratford Hotel each morning commencing Monday, October 8 from 10 a. m. to 12 and each afternoon at the Commercial Museum commencing Monday at 1 p. m. to 5. A registration fee of $1 will be charged members and their male guests. Registration is required as admission to Commercial Museum, and many of the social events will be by badge only.

Technical Discussion

(Reprinted from Aug. 9, 1928, issue *Engineering News Record.*)

During the last decade society activity in the engineering field has been developing rapidly. Today it is clearly an essential agency of professional growth. Yet one of its basic elements —namely, discussion—has lost rather than gained vigor as the development proceeded. Meeting after meeting shows only anemic attempts at comment and exchange of opinion concerning the problems dealt with in the prepared papers. Lacking the stimulative massing of experience through

pertinent discussion, technical meetings become mere lecture sessions—by no means the best return for the large investment of time and thought which the meetings represent. Is increasing specialization at fault, or are we becoming a silent profession? Are program arrangements such as to inhibit discussion through overcrowding and lack of time? Doubtless all of these factors play a part, but more probably habit is the determining influence. And this habit is shaped almost wholly by the older men. Where the seasoned veterans of the profession are content to sit as silent hearers, juniors are unlikely to venture upon debate. If we are to have a revival of technical discussion, then, it is to the elders that we must look for leadership in the movement. Certain it is that the society which makes a start toward reanimating discussion can look for large returns.

SECTION ACTIVITIES

Chicago

The Chicago Section held its first meeting of the season on Sept. 14. Reels No. 1 and 2 of the Gas Products Association's films were shown. Following these films, the speaker of the evening, Dr. L. Andren, chief metallurgist of the Research Department of the American Chain Company, addressed the meeting on the subject "Welding Metallurgy." The paper was accompanied by lantern slides.

Los Angeles

The September meeting of the Los Angeles Section was held on the 5th. Mr. Llewellyn of the Airco-Davis Bournonville Co. was the speaker of the evening. This was also the annual meeting.

Philadelphia

The regular meeting of this section was held on Sept. 17. Mr. W. M. Dunlap, Technical Direction Bureau, Aluminum Company of America, presented an interesting paper on "The Welding of Aluminum."

Detroit

The Westinghouse Electric & Manufacturing Company has very kindly arranged to give a demonstration of the "electrical man" at the Detroit Edison Service Building, 2000 Second Avenue, Wednesday evening, Sept. 26, at 8 o'clock. The Detroit Edison Company has very kindly extended an invitation to the members of the American Welding Society to witness this demonstration.

The "electrical man" is a scheme for performing substation switching operations by means of an ordinary telephone line under the control of an operator at some distant point. The "man" is made to go through his paces by sending sounds of different pitch to him over an ordinary telephone line. The demonstration is exceedingly interesting.

EMPLOYMENT SERVICE BULLETIN

SERVICES AVAILABLE

A-79. Acetylene welder desires position. Have had eight years' experience as repair welder and cutter. Last two years have been technical school manager and instructor in welding jobs and technical advisor for safety committee. Have worked for Curtiss Aeroplane and Motor Company. Can give good references.

Standard Line of D. C. Machines Fabricated by Arc Welding*

By R. S. MARTHENS†, C. C. BRINTON††, AND F. T. HAGUE†††

DIRECT current machines have not been the first to be completely fabricated by electric arc welding. Electrical manufacturers have generally followed through the development of simpler types of A.C. synchronous machines, accumulating experience in fabrication and developing correct welding technique as applied to electrical structures, before undertaking the fabrication of the direct current machine. Under these circumstances, the completely fabricated D.C. machine can reasonably be expected to benefit from this already accumulated manufacturing experience.

An existing line of D.C. machines using castings, cannot be changed over to the arc welded fabricated construction simply by replacing castings with similar fabricated constructions, without sacrificing many of the attractive possibilities which the new method of construction makes possible. A particularly valuable feature of fabricated construction in D. C. machines of medium and large size is the design flexibility of the arc welded construction that permits a wide application of any given element of the machine. This feature alone has an economic aspect which justifies the complete redesign of the entire line of machines to take full advantage of all the opportunities of flexibility in design which the arc welded fabricated construction alone makes possible.

The direct current machine is essentially one for specialized applications, and as a result, individual types of construction using castings have been developed for mill, hoist, marine, and engine driven applications. Individual lines of electrical ratings have been developed for each type of service, but continual development in these industries and application changes have effectively prevented extended duplication of specific ratings or any promise that the future will be any more stable than the past. The present demand is for special electrical ratings and constructions, and this must be met with low cost apparatus, unburdened by high development charges. The arc welded fabricated construction makes possible the necessary flexibility in design to meet these requirements in D.C. machines.

It is not proposed to fabricate the largest or smallest sizes of D.C. machines at this time. Lying between the class of special large machines that must be built to order, and the standardized small industrial product built for stock, is a large and important class of medium size machines that constitute a particularly difficult design and production prob-

*To be presented at Fall Meeting, A. W. S., October, 1925.
†Mechanical Engineer, ††Manufacturing Engineer, †††Division Engineer, Power Engineering Department, Westinghouse Electric & Mfg. Co.

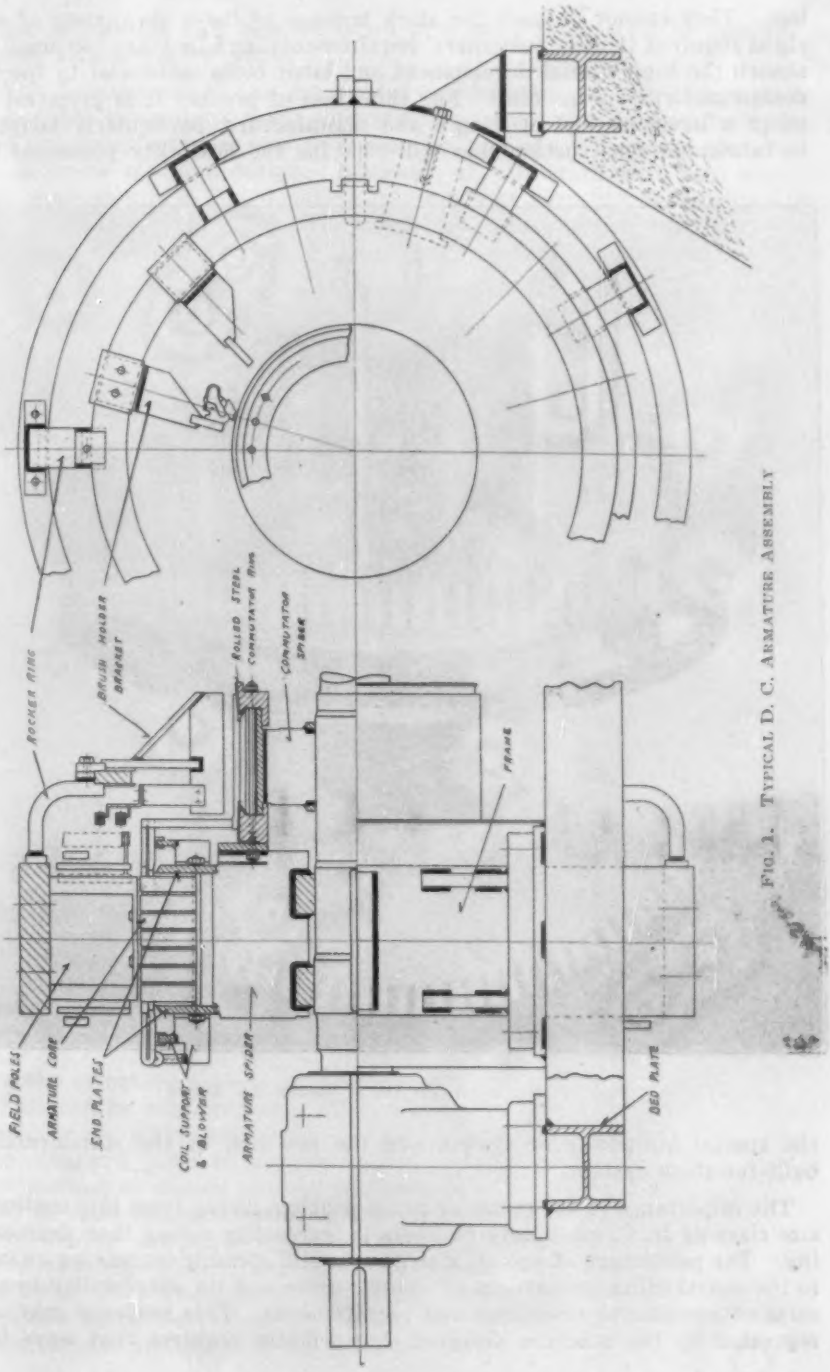

FIG. 2. TYPICAL D. C. ARMATURE ASSEMBLY

lem. They cannot be built for stock because of the wide variety of designs required to meet customers' requirements, and they are too small to absorb the high special development and labor costs incidental to special design and custom building. For this class of product it is proposed to adopt a novel method of design and manufacture, particularly adapted to fabricated construction that will combine the flexibility possessed by

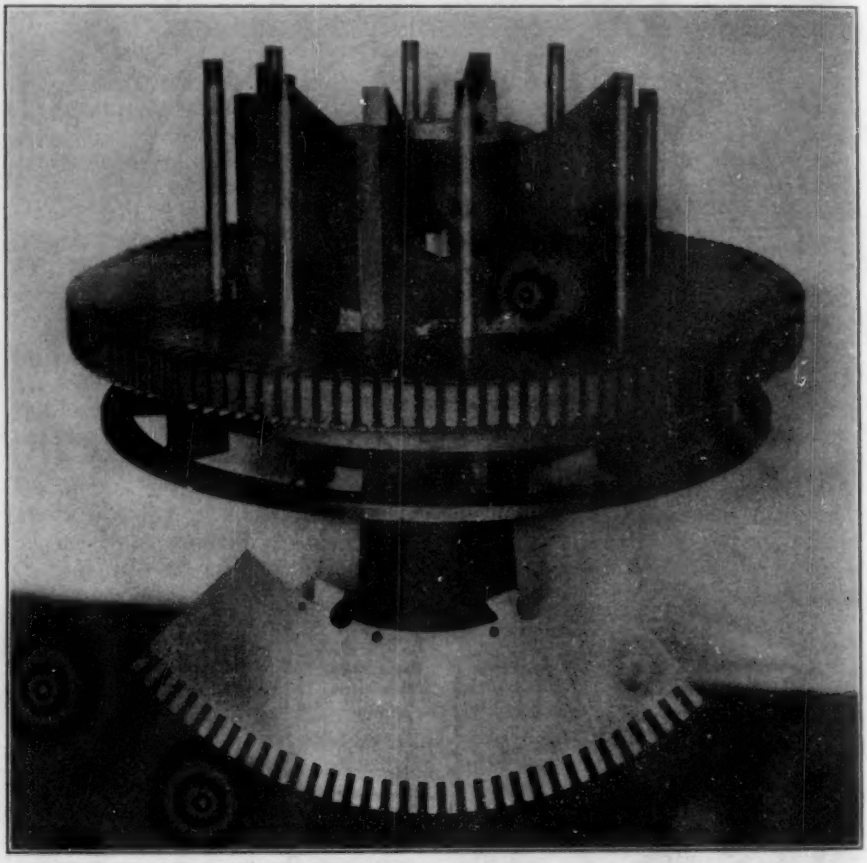

FIG. 2. BUILDING UP D. C. ROTOR ON BOLTS

the special built-to-order system and the low cost of the standardized built-for-stock system.

The importance of the manufacturing problem rising from this medium size class of D. C. machinery business is increasing rather than decreasing. The percentage of special machines is still steadily increasing owing to the outstanding advantages of electric drive and its adaptability to all sorts of mechanical conditions and requirements. This tendency may be regretted by the machine designer, but wisdom requires that ways be

found of meeting this new condition with as little sacrifice in manufacturing economy as possible.

The development of the arc welded fabricated construction has made it possible to combine these contrary requirements of design flexibility and low manufacturing cost by the application of the standard part idea to electrical machine design. Basically, the standard part plan means the separation of a D.C. machine into parts or elements, some of which can be used in all different designs and others which will generally change with every design. The major mechanical elements such as

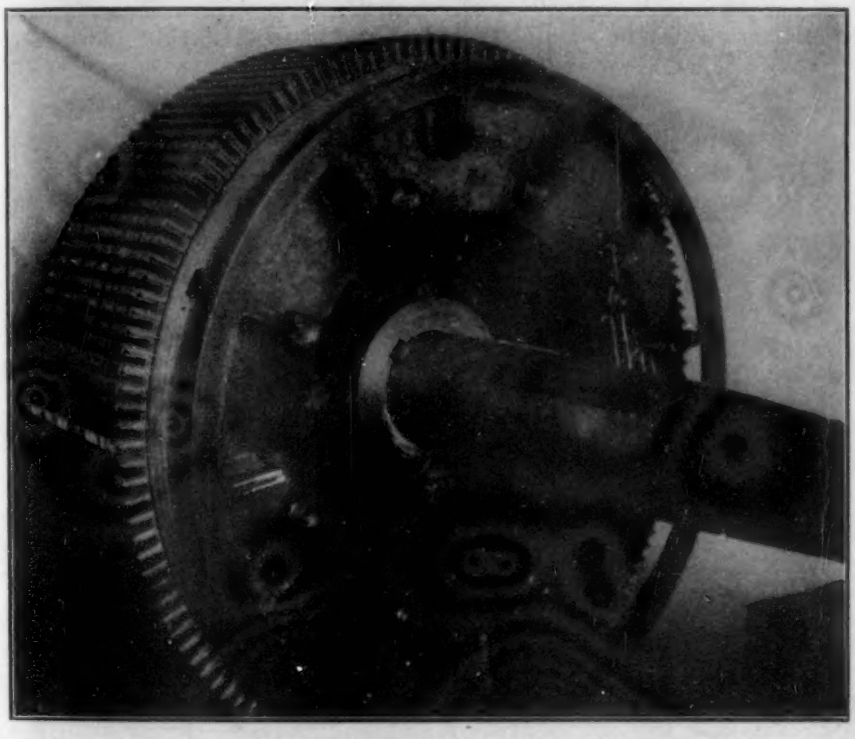

FIG. 3. COMPLETE D. C. ROTOR

frames, armature spiders, punching blanks, are obviously constant parts which can be standardized. Windings in general are variable elements that change with every rating. The purpose of this plan is to reduce the standard parts to a minimum number of sizes and to so organize the method of design of complete machines that a given standard part will be used throughout the entire range of rating within the scope of this line of machines. The fabricated construction alone makes this plan feasible without incurring prohibitive development charges for patterns, etc. There is nothing new in the standard part idea itself; the new thing worthy of note is the application of this old idea to the fabricated construction of the internal parts in complicated direct current

electrical machinery, in such a way as to meet exact performance requirements.

Successful application of this idea requires a complete change in the designer's objective and method in designing the entire line of machines. The unit of design is no longer a single rating with the problem of making the best possible special design for that rating alone. The new unit is a single part—a frame, main pole, armature punching, commutator, etc.

The problem is to design that part so that the desired range of ratings can be built satisfactorily with competitive performance, with the minimum number of sizes of that part, and to so design the individual

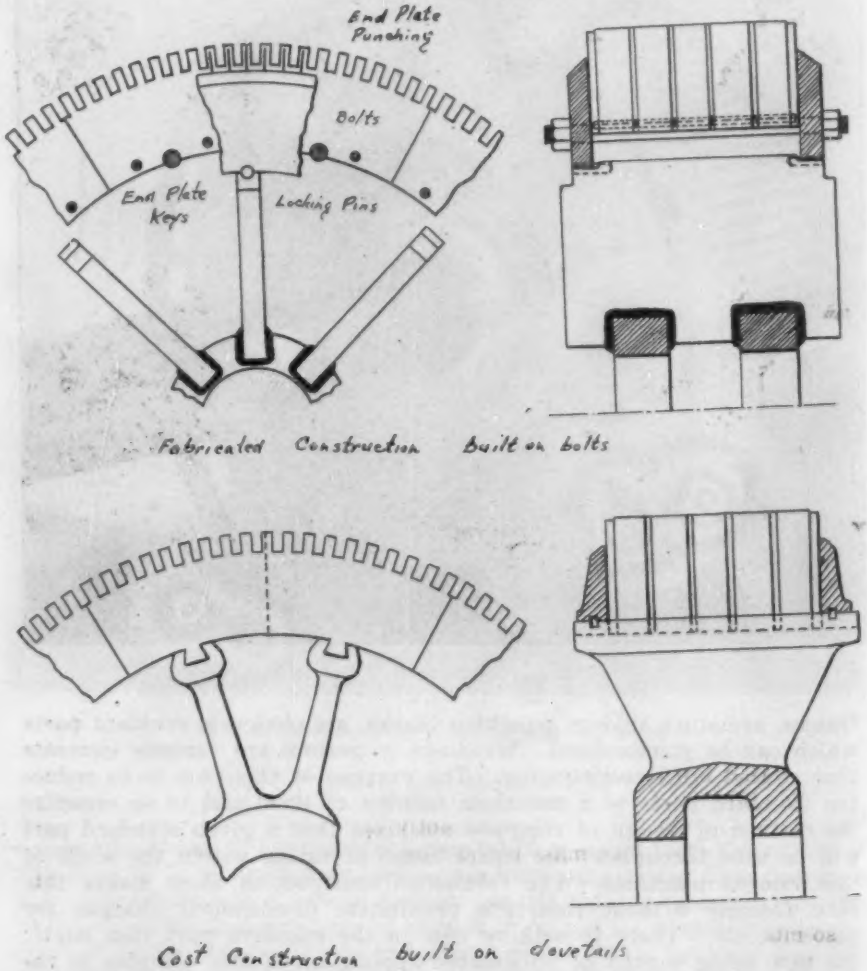

FIG. 4. NEW AND OLD STYLE PUNCHING AND SPIDER DESIGNS

part that it will have a rational application when assembled into completed machines. Some parts of the machine will necessarily vary with every rating, but these parts are essentially electrical and are not important from the standpoint of welding applications. The essence of the standard part plan of fabricated construction is to so simplify the design of the product that mass production technique can be applied, as it is recog-

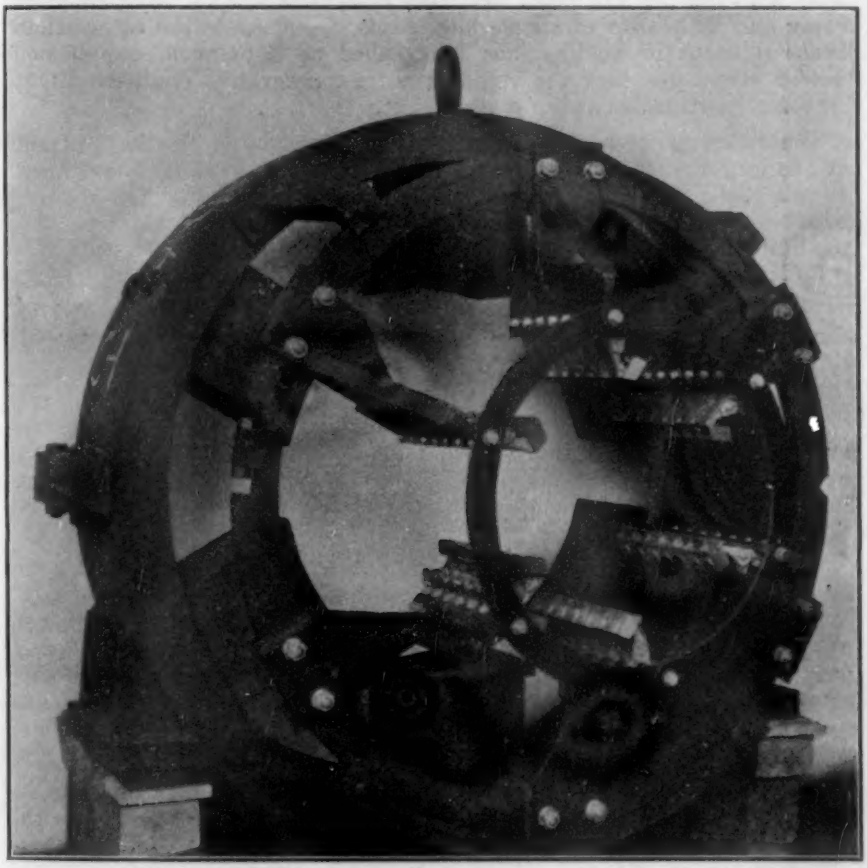

FIG. 5. ROLLED STEEL FRAME AND BRUSH RIGGING

nized that low manufacturing costs result from standardization and mass production. It has been pointed out that in this D.C. machinery business we are not dealing with a sufficiently large volume in number of units to be concerned with mass production methods. The real significance of mass production, however, is not so much the quantity of production as it is the simplification of the product. The important concept is not so much large quantity as it is small variety of design.

The standard part plan of fabricated construction greatly simplifies the welding problems by reducing the variety of welds to a small num-

ber of standard types. For each of the relatively small number of standard parts, a master design is created and each element manufactured is identical in design, and differs only in physical dimensions. The manufacturing problem, and the welding technique required can obviously be given the utmost consideration in view of the limited number of such parts involved. As an example, it has been found possible with but one exception to design the entire line of standard parts using only four sizes of simple fillet welds. Skill in design rather than brute strength in welding, has been called upon to avoid complicated welded structures that the timid or ultra-conservative engineer might consider questionable at the present time.

The following general principles were adhered to in the development of the larger sizes of this line of completely fabricated D.C. machines. In analyzing these principles it must be kept in mind that the application of arc welding to the rotating members of D.C. machines is relatively new, and that ultra-conservativeness in the welding application is considered desirable at the present stage of the development.

The mechanical safety of the rotating armature member must not be dependent upon the security of any welding. This favors the use of through bolts to hold the armature core and commutator together, and the use of rolled steel V rings.

The centrifugal forces of the rotating armature core and winding must not be carried by any welded joints. The armature core is built up of laminated segmental punchings so interlocked by steel pins that the entire unit is a self-supporting ring merely centered and driven by the fabricated spider.

Unyielding elements which are rigidly held apart and are unable to approach each other slightly when the welding metal cools, should not be joined together by welding. As an example, armature spider arms are not welded to both the unyielding hub rings and the armature core element. They are welded to the hub ring only and are attached to the core through a simple mechanical press-fit connection. Avoiding difficult welded structures eliminates the necessity of annealing parts after welding.

Electric current is not carried through any welded joints in the brush rig construction owing to the unestablished factors in connection with the resistance and electrical stability of welds.

Simple fillet welds of small size should be used. Welds of large cross-section are not preferred in that they require a large amount of welded metal per unit of strength and are less readily inspected than small welds. Being built up in successive layers, the large weld is rather more subject to unequal stress distribution due to temperature effects during cooling.

Stresses in welds must be ultra-conservative even under the condition of short circuit on the machine. The value of short circuit torque has been determined and a large factor of safety has been used in the application of the welds. On the rotating part, the steel pieces joined together must be stronger than the weld.

The shape of the replaced casting need not be maintained in creating the new fabricated element. Very often it is found that an efficient design for fabrication takes a shape entirely different from that of the obsolete casting, and the new shape can be made more nearly the ideal for strength.

A small number of stock size bars, sheets, slabs and structural shapes should be required to cover the entire line of design. Proper planning in this respect is required to maintain a minimum scrap ratio and will be repaid by low costs.

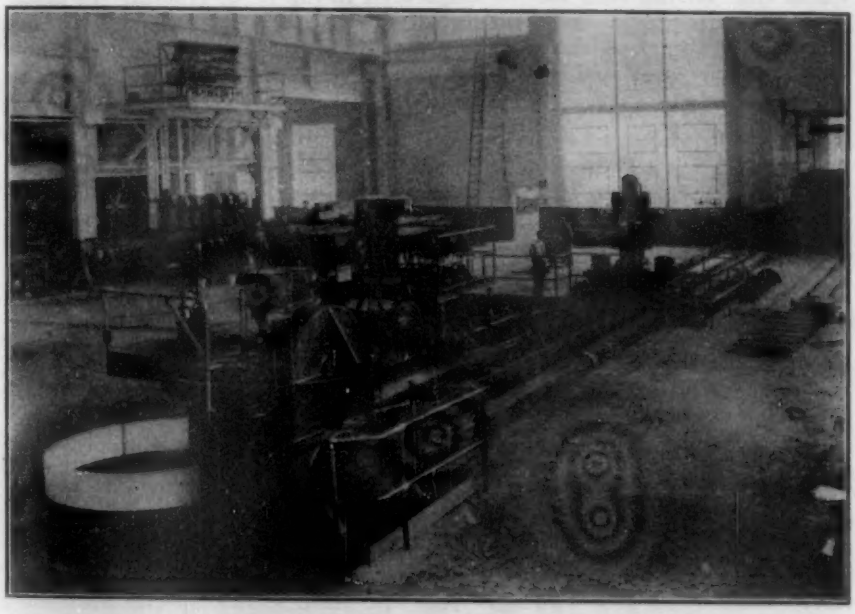

FIG. 6. GENERAL VIEW OF SLAB BENDER EQUIPMENT, SHOWING FURNACE, CRIMPING PRESS AND VERTICAL THREE ROLL BENDER

The designs must be so made in conjunction with the manufacturing engineers that proper allowances and tolerances will be made for mill variations in the dimensions and flatness of steel shapes, the unevenness of burning, and the distortion due to welding. The sequence of manufacturing operations which will give low cost very often calls for new ideas. With fabricated steel parts, it is frequently possible to entirely omit certain machining previously required in the use of castings. The designer must keep in close contact with the manufacturing engineer, as many new developments may thereby be applied to parts other than the one which led to their inception.

The control of the design of shop tools and fixtures is an integral part of the design of the machines themselves. The problem of tools and fixtures is more difficult with fabricated steel parts than with castings, one of the reasons being the greater flexibility inherent in the fabricated

designs. It is essential that this flexibility should not be restricted too greatly by shop tools and fixtures, and it is frequently a problem whether to provide a universal fixture, or one applying only to a particular size part.

The fabrication of a line of machines requires considerable special factory layout and equipment. The full advantages available from the arc welded construction can only be realized by courageous scrapping of existing manufacturing equipment, and the installation of new equipment of novel type. In place of the foundry, there will be substituted furnaces and bending rolls for the rings used in the D. C. frames. In place of the machine tools, there will be automatic gas cutting machines, and finally, automatic welders, etc., required for fabricating. Thus, there are heavy initial development costs that must be incurred before manufacturing can begin.

The factory layout for the manufacture of D. C. machines is to some extent merged with other lines of a similar character. It is a more simple problem for the manufacturing engineer to make an efficient and economical layout to manufacture fabricated machines than it has been in the past when castings were used throughout. The storage of the required stock of parts, the handling of these parts, and the performance of various operations, has been worked out to suit the new material used. This has, of course, required a complete rearrangement of the existing manufacturing layout.

The manufacture of the various parts is laid out so that the cutting, cleaning by shot blast preparatory to welding, and the welding itself, is completed with a minimum of handling. Frame rings are bent, cleaned, and accessories welded on in the same shop section by one single group. The rotating parts, however, are handled by a separate group on account of the higher grade of workmanship required by the rotating part. The small variety of types of designs has been found to facilitate good welding. The welders of this group are selected from those who have received training in the welding school and have shown special aptitude in regular production work in other less important groups. The supervisors and inspectors are chosen with a view to securing good welding and reliable inspection of the welding process, as well as the finished product.

Special equipment is essential to produce the parts for the D. C. machines, some of which it has been necessary to develop in order to meet the requirements of manufacture of heavy frame rings. The equipment for making these rings includes a furnace for heating the heavier slabs for bending. It is necessary to heat slabs of more than 3½ in. thickness before they can be formed into rings. A set of motor-driven roll tables with hydraulic turn-over apparatus, handles these slabs from one operation to the other. A crimping press and a vertical three-roll bender completes the equipment for the manufacture of the rings. The crimper is a 1000 ton hydraulic press equipped with dies for bending the slab ends before going through the bender. This makes it unnecessary to cut off or bend by hand the straight ends left when such rings are bent in a three-roll bender. It is unnecessary to provide a die for each diameter

as one die can take in a range of diameters by proper manipulation of the press. The press is supported on roller trunnions so that it can spring with the piece being bent, thus allowing the rest of the piece to be flat on the roll table. After crimping both ends, the roll table carries the piece to the "pick-up," which turns the slabs on edge ready to be entered in the bender.

The bender is a vertical three-roll machine with motor-operated rolls and an individual motor-operated screw-down. The screw-down is made heavy enough to bend the piece by centering the slab and operating the screw-down motor. This makes it possible to begin the bending opera-

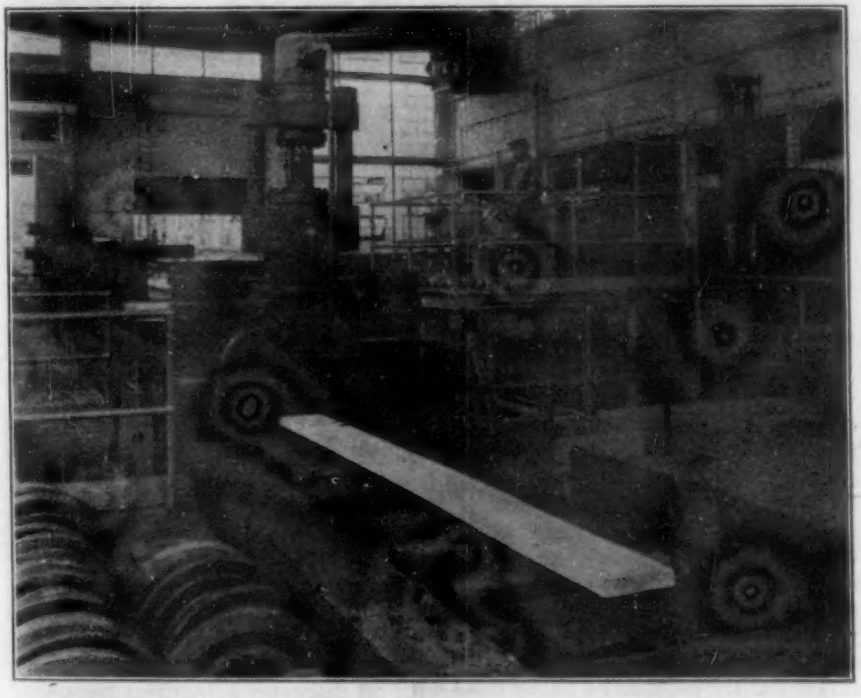

FIG. 7. CLOSE UP VIEW OF CRIMPING PRESS

tion from the center of the piece if desirable, or to bend without allowing it to pass out of the rolls. Guide rolls are used to support the free ends of the rings to prevent possible distortion while bending. The bender is capable of handling a slab 36 in. wide and 3½ in. thick without heating. The smallest diameter ring that can be made is 30 in. with no limit to the maximum. It will also edge-bend rings 2½ in. thick and 12 in. wide to 60 in. minimum diameter. The controls are centralized at a pulpit placed so that the furnace door and car, roll tables, crimper and bender may be under the control of one man who can oversee all of the operations.

The welding fixtures are all made from structural shapes and completely welded together, taking advantage of the adaptability of this material for such parts. The fixtures have been designed with particular attention to

securing the best arrangement for assembling the parts and ease of welding. These welding fixtures, wherever possible, are made so that only one fixture is required for each part of the line, regardless of its size. This feature has been secured with no sacrifice of the adaptability of the part or undue complication of the fixture. In order to take the greatest advantage of the possibilities inherent in this type of construction, it is necessary to allow much less stock for machining than has been needed for castings. To accomplish this result, adequate welding fixtures must be provided so that the parts are held in proper relation to each other and the welding done in a way to produce the minimum distortion of the finished parts.

The raw material necessary to manufacture both the rotor and stator is carried in stock either in mill lengths or multiple lengths for that part for which it is to be used. The investment needed for a complete stock of this kind is very small compared with that which would be needed to carry an equivalent stock if castings were used. It is quite probable that the investment and the handling of a complete stock of castings for such a line of machines would be prohibitive under any manufacturing conditions.

In the following discussion, the details of a few of the major parts will be made clear by referring to the Sectional View of a typical machine.

The magnet frame is made up of steel bars and slabs joined together by arc welding. All welds are located on the outside and are of the simple fillet type. The frame foot welding must withstand the stresses due to electrical short circuits of the machine and these welds have been calculated to have an ample factor of safety under this condition. The welding at the split of the frame and the lifting lugs is determined by the weight of the parts and the permissible deflection of the frame rather than by load torque conditions. These welds have been calculated to withstand the stresses due to handling in the factory and installation of the assembled stator. The number of bar and slab stock sizes required for a line of frames accommodating armatures from 25 in. to 100 in. in diameter, is surprisingly small. For 30 frame sizes, only 5 bar sections are required for frame feet, 5 sections for foot ribs, and 6 sections for lugs at the frame split. The shop welding fixture for these frames is a universal fixture capable of being used with all diameter armatures between 25 in. and 100 in. In this welding fixture provision has been made for locating the frame feet at any desired height as required by the machine installation.

A desirable saving is made in development by the elimination of the patterns and the continuous changing of patterns to obtain the foot height required in different installations. Delivery time is also reduced as a natural result of fabrication, in that there is no pattern to make or remove from storage, no likelihood of scrapping castings and the machining time for the fabricated frame is considerably less than that of the cast frame.

The brush rigging is of the conventional rocker ring and brush holder bracket type and is completely fabricated, all pieces being held together by arc welding. It is believed that fabricated steel parts have a greater

tendency to vibrate than do cast parts and this has been recognized in the layout of the new structure. Various samples have been built and their comparative rigidity tested. The final design is a rugged rigging more capable of standing severe service than the replaced cast design.

All welds are of the outside fillet type, the parts being so arranged that electric current does not carry through any of the welds. The rigging is made in halves, being bolted together to facilitate installation and

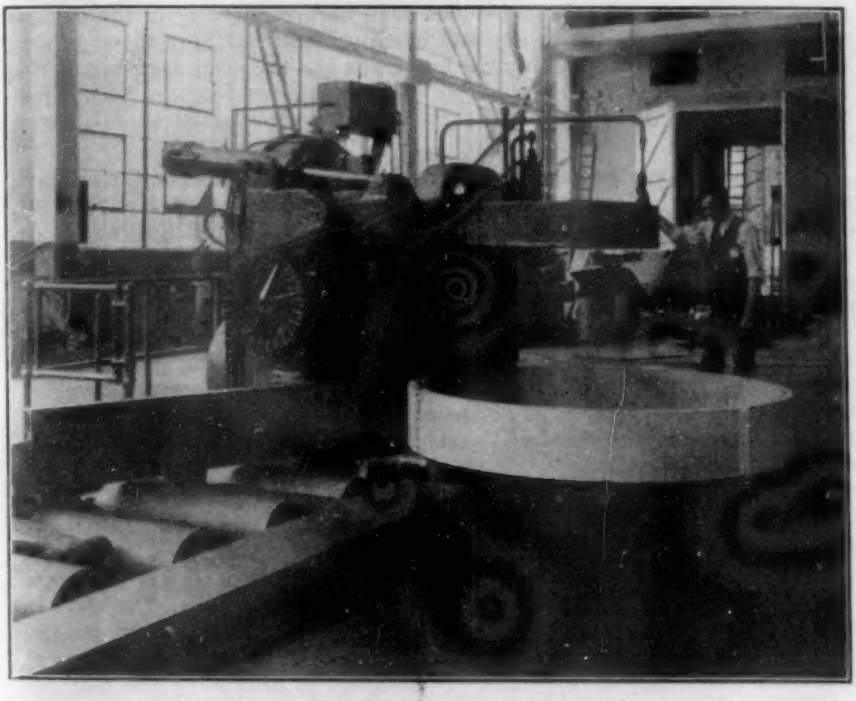

FIG. 8. CLOSE UP VIEW OF VERTICAL THREE ROLLER BENDER

dismantling in case of repairs to the machine. The rigging is also capable of being readily shifted to obtain the correct electrical neutral position.

The brush holder brackets are made of two steel bars joined at right angles by arc welding, the horizontal bar being notched to receive the vertical bar. Rigidity is obtained by a brace between the outer end of the horizontal bar and the vertical bar.

The shop tools and fixtures for the brush rigging include a fixture for holding the rocker ring supporting arms in position while welding the blocks at either end, a planing fixture for these arms, a drill jig for one pair of brush holder brackets, a welding fixture for the brush holder bracket members, a machining fixture to assure true faces as required on these brackets, and a drill jig for the brush holder bolt holes. For the brush holder brackets of the 30 machine sizes only two bar sections are

used for the horizontal members and two sections for the vertical members, with two sections for braces. Three standard channels are used for the brush holder supporting arms and three bar sections are used for the shift rings to which the brush holder brackets are attached.

The armature spider is composed of two hub rings and the necessary arms, both burned from steel plates. The spider arms are notched by gas cutting to receive the hub rings. The end plates, as well as the commutator supporting ring, are also burned from steel plates. As previously noted, certain very definite principles have been adhered to in the design of the rotating welded members and much thought has been given to the type of welding used in joining the hub rings and the arms together. With the arms notched to receive the hub rings, ample welding can be applied to obtain very conservative weld stresses under the most strenuous operating conditions.

The armature spider construction is, of course, dependent on the method used to build up the armature core. In this line of machines the armature core is built up on bolts which extend through both end plates and maintain pressure on the laminated core. The core and end plates are self-supporting, in so far as centrifugal forces are concerned as is made evident by the sketch, and the spider serves only to center them and transmit the torque to the center of the machine. The connection between the end plates and the spider arms is made by a shrink fit and fitted dowels. The commutator supporting ring is burned from a plate and is welded to the end of the spider arms. These welds are capable of withstanding the pressing-on of the shaft of the completed rotor as is required in some engine type applications.

The only stress in welds and hub rings is that which is set up by the transmission of the torque and this is easily determined for any specific design. Sample armature and hub rings have been made and tested with several amounts of welding. In the final design, a structure has been selected wherein the welds are much stronger than the steel in the arms. With this type of rotating part design, a much more rugged rotor is obtained than is possible by the use of castings and the old type of mounting punchings on dovetails. In addition to improving the mechanical safety of the rotor, the new construction is much more open and by giving better ventilation, insures more output from the machine.

The number of stock sizes required is surprisingly small, considering the possible variations in shaft diameter and core length covered by the complete line of machines. It has been possible to design 68 combinations with only eight bar sections for the spider arms and two plate thicknesses for the hub rings, end plates, and commutator supporting rings.

With this type of design the factory cost of the rotor is not materially different from that of the cast construction when cast iron parts are strong enough for severe service. However, the structure is greatly superior to any cast design from the strength standpoint. Manufacturing time is also reduced by the elimination of the former machining of dovetail slots in the spider casting. This element is a striking example of important improvements which are frequently developed as the result of introduction of a new type of construction.

Maximum Allowable Working Fiber Stresses in Welded Structures*

S. W. MILLER†

THE question of what working fiber stress should be used in designing any structure has always been in the minds of engineers. Economy demands the least possible amount of material, while safety urges the engineer in the other direction—that is, to put plenty of material in so that the structure will surely be safe. The allowable fiber stress depends somewhat on the conditions under which the structure operates, but it seems evident that the most important thing to be considered is that in service the structure must not permanently distort under any stress that may be applied to it. There are cases in which a reasonable amount of temporary distortion is permissible, and other cases in which such distortion must be limited. For instance, a steel I-beam will stand without danger a certain load, but in many cases the deflection due to that load is too great to permit it to be used in a plastered ceiling if the plaster is expected not to crack, though in neither case is the metal of the I-beam permanently distorted. Permanent distortion cannot be allowed.

Steel has the property of perfect elasticity under stress up to a certain point, which is called by various names, such as yield point, proportional limit and elastic limit, all of which are very close together in amount when measured, as usual, in pounds per square inch, and which are really variants of what we call elasticity—that property of matter which causes it to return to its original dimensions after it has been deformed. Evidently, structures in service must retain their elasticity to be of value. To be accurate, the above can be applied only to material that is homogeneous. Actually, there is no such material, but if we had it we could rely on its elasticity being the same in all parts and in all pieces. Fortunately, good steel is sufficiently homogeneous to enable us to design and build structures that are perfectly safe in service.

If we knew in any particular case the exact maximum stress to which a structure would be subjected in service, and if we had homogeneous material, we could use in the design of the structure a stress very close to the point at which the law of elasticity fails. However, we cannot know the stresses to which a structure is subjected in service, nor do we have homogeneous material. We are, therefore, forced to use in our design a less stress than that referred to—how much less depending purely on experience and the judgment of the designer.

The ratio of the theoretically possible stress to the one actually used may be called a factor of safety. Usually, however, the factor of safety

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is taken as the ratio between the ultimate strength of the material and the actual working fiber stress selected.

Let us consider the case of mild steel of an ultimate strength of 55,000 lb. per sq. in., having a yield point of 35,000 lb. per sq. in. According to the previous argument, if the material were homogeneous and we were sure that no greater stress than 34,000 lb. per sq. in. would ever be applied to it, we could safely use a design fiber stress of 34,000 lb. As a matter of fact, in this country, when such material is used for boilers, a working fiber stress of only 11,000 lb. is permitted by the A. S. M. E. Boiler Code, while for the same material in locomotive boilers a stress of 12,200 lb. is permitted, and in England for stationary boilers 13,750 lb. is allowed. All of these are below the yield point of the material, but even the highest of them is nowhere near the yield point. The highest is 25 per cent greater than the lowest, and it may well be asked what reason is there for this 25 per cent variation. I am perfectly willing to admit that I do not see any, and I do not believe that any other conclusion can be reached than that we are, in this country, following a custom of many years' standing without any definite knowledge on which to base our design.

I do not intend in any way to condemn the use of a factor of safety of 5 in boiler construction. My only purpose is to point out that our factors of safety are not based on definite knowledge that we rightfully should have. It is very probable that the factor of safety of 5 used in boiler construction is on the safe side.

I think that it will be admitted by everyone that a certain amount of ductility is necessary in any structure subjected to unknown stresses, although we have no definite information as to the minimum amount needed in any particular case, except that we find from our experience that a certain structure, having a certain ductility in its material, has proved safe. In ordinary steel construction work (and I am not referring to the case of structural steel so called), it may be said that as a general rule the factor of safety used in design is 5. In the case of structural steel in buildings, the usual factor of safety is about 4, and 16,000 lbs. is the usual design fiber stress. It is well known that this is considered by many engineers to be lower than is necessary, and there is a strong movement to increase it to 18,000 lbs. But let us assume for the present purpose that the customary factors of safety referred to above are all right, and that whatever the reasons may be, it is not desirable to change them.

In welded construction in which mild steel is used, of course the same problems of design are encountered as with other types of joints. We must assume, in discussing welded joints, that we are talking about properly made ones, because we cannot admit that we would base any design on bad material or construction. Assuming that proper procedure is followed in making, for example, a welded pressure vessel, we can have no doubt as to the tensile strength of the weld metal or of the base metal, because these can be easily determined by the tensile test. This has been done numberless times, and many results have been published. In a general way, it can be said that this tensile strength runs from 45,000 to 75,000 lbs. per sq. in., depending on the welding rod and process used, and this refers to welds that have not been heat treated. With

mild steel plate, then, there is evidently no difficulty in obtaining sufficient tensile strength in the weld to break the plate.

It should also be understood that these figures refer to tests made with the reinforcement on the welds ground off. We are not concerned in the present discussion with what may be done in the way of strengthening the weld by reinforcing, but only with the strength of the weld metal. If a welded test piece with no reinforcement breaks outside the weld, it is obvious that the weld is stronger than the plate, and that as far as tensile strength is concerned, we will be perfectly safe in using this figure for the tensile strength of the weld metal, so that we can safely use the breaking strength of the test piece (regardless of whether the rupture occurred in or out of the weld) for our present purpose.

The ductility of welds also varies with the welding rod and the process of welding, but it would seem perfectly fair, and indeed almost obvious, that two welds made by different processes or with different rods, but which have the same tensile strength and ductility, should be allowed the same working fiber stress, for the present disregarding its amount.

The measurement of the real ductility of weld metal is impossible in an ordinary welded tensile test piece, because the yield point of the weld metal in mild steel, when its tensile strength approximates that of the plate, is always higher than the yield point of the plate, so that during the tensile test the base metal elongates and begins to neck down before the weld metal does. As an illustration, the yield point of the majority of welds is in the neighborhood of 42,000 to 45,000 lb. per sq. in., while the yield point of ordinary mild steel is about 35,000 lb., and as most of the elongation in any tensile test piece occurs during the last few thousand pounds of the load, the result is a comparatively small elongation in the weld metal, its real ductility not being shown. For instance, certain weld metal has an ultimate strength of 70,000 lb. per sq. in. and an elongation of 25 per cent in 2 in. in a standard .505 in. test piece. Nothing like this elongation can be obtained in an ordinary welded tensile test piece, as the results will show only about 10 per cent elongation in 2 in. over the weld, and much of this 10 per cent is in the base metal.

We have studied this question rather thoroughly in our laboratory, with the result that a properly made bend test is found to show much more closely the actual ductility of weld metal. The essential feature of the test is that there must be no restraint at the bend during its making, which is done by slightly kinking the piece at each end somewhat outside the weld, say an inch or so from it, and then bending it endwise as a column in a testing machine, vise or press.* At the first sign of cracking, the bending is stopped, and the distance between the gage marks previously laid out in the weld metal again measured, the elongation being measured the same as in the usual tensile test. This being also a test of the weld metal, the reinforcement should be ground off.

There is no great difficulty in bending test pieces ½ in. thick in an

*Paper by A. B. Kinzel read at the September, 1927, meeting of the American Society for Steel Treating in Detroit, Mich.
See also paper by W. B. Miller in the Journal of the American Welding Society for September, 1927.

ordinary heavy vise, but with thicker material the facilities usually at hand are not sufficient. In such cases, a piece is taken from the top of the weld or the bottom, or both, of suitable thickness, say 3/8 in., which piece is bent in the usual manner.

It is quite common, although not universal, to record in a tensile test the per cent, reduction of area, and many engineers believe that this is a better measure of ductility than the elongation as usually given. It is interesting to note that the bend test combines both the elongation and reduction of area, and for this reason is a better measure of the ductility, in my judgment, than pure elongation. After all the elongation measured in 2 in. or 8 in. does not give a true idea of the ductility of the metal. In an 8 in. test piece, the original inch in which the greatest elongation takes place may have stretched in mild steel as much as 90 per cent, while the total elongation may be 30 per cent. The elongation also depends on the geometry of the test piece. The reduction of area, taking place in a short distance, is not subject to these variations, so that any test that includes even a portion of the usual reduction of area, gives, to my mind, a fairer measure of the ductility than the result that is based on the usual elongation figure. I believe this to be true, not only of weld metal but of all metals.

In any case, the bend test seems to be the only method by which the ductility of the weld metal can be determined with reasonable accuracy, so that if the results of this test could be combined with tensile strength in some way, it would seem that reasonable decisions could be made as to the proper fiber stresses that could be allowed in welds of different kinds.

As there seems to be no theoretical basis for a working fiber stress, it is necessary at present to depend on practical results for the development of any formula that would be used for the purpose. If we know that certain fiber stresses have been used successfully with welds of certain tensile strength and elongation as measured by the bend test, we can create a formula to cover these results. Of course, the more figures we have the more accurate will be the formula, which undoubtedly is true of any formula that is empirical; but an additional element of accuracy that it is fair to consider, is the opinion of engineers based on their experience as to allowable fiber stresses for different kinds of welds. The tensile strength and elongation of such welds can be determined and the formula checked against them.

It would also seem fair that the formula should take account of ductility in such a way that a lower working fiber stress would be allowed where the material has low ductility, and that the working fiber stress should depend directly on the tensile strength.

Such a formula has been devised by Mr. A. B. Kinzel, and is as follows:

$$S = \frac{T}{7.15} \sqrt[3]{\frac{E}{10}}$$

in which S is the allowable working fiber stress, T the ultimate tensile strength, and E the percentage of elongation as determined by the bend test before referred to.

Using different values for T and E, Table I* has been prepared. The factor of safety in the last column is the same for any given percentage of elongation. The ultimate strength is either that of the weld metal if the weld breaks during the test, or of the base metal if the fracture occurs in it, and obviously a structure cannot be designed, as far as tensile strength is concerned, except on the strength of the weakest part. It is easily worked out that a factor of safety of 5 is reached at an elongation of somewhat over 29 per cent.

TABLE I

Proposed Maximum Allowable Working Fiber Stresses in Lbs. per Sq. In. of Plate Section for Welded Steel Pressure Vessels

Per Cent Elongation by Bend Test	Ultimate Strength in Thousands of Lbs. per Sq. In.							Factor of Safety
	45	50	55	60	65	70	75	
5	5,000	5,600	6,100	6,700	7,200	7,800	8,300	9.
7½	5,800	6,400	7,000	7,700	8,300	8,900	9,600	7.8
10	6,300	7,000	7,700	8,400	9,100	9,800	10,500	7.15
12½	6,800	7,600	8,300	9,000	9,800	10,500	11,300	6.65
15	7,200	8,000	8,800	9,600	10,400	11,100	12,000	6.25
17½	7,600	8,400	9,300	10,100	11,000	11,700	12,700	5.9
20	8,000	8,800	9,700	10,600	11,400	12,300	13,200	5.7
22½	8,300	9,200	10,100	11,000	11,800	12,800	13,700	5.5
25	8,600	9,500	10,500	11,400	12,400	13,200	14,200	5.3

Any change in the constant, 7.15, would change the fiber stress in direct proportion. For instance, if 7 were taken instead of 7.15 the difference would be only 2 per cent, which is evidently of practically no effect. The only reason why 7.15 was used is because it fits more closely the results of the tests on which the formula is based.

The part of the formula covering the factor of elongation decreases the allowable working fiber stress more rapidly than the elongation decreases, and on the other hand, increases the fiber stress more slowly than the elongation. This seems quite logical, because there must be a point beyond which an increase in elongation increases the value of the metal but slightly, and because as the brittleness increases the metal becomes less reliable in service.

It may be asked why some other root than the cube root was not used in the preparation of the table. It is because the cube root seemed to fit the facts better than did any other. Table III compares the results by using the square root and the fourth root with the results of Table I. It will be noticed that while there is not so much difference in the central part of the table, yet at the extremes, both of tensile strength and elongation, there is a large difference. The figures for the square root formula are about 12 per cent less for 45,000 lb. and 5 per cent elongation, and for the same basis about 6 per cent greater for the fourth root. At the other end of the table, for 75,000 lb. and 25 per cent elongation, the square root gives an increase of about 17 per cent, and the fourth root a decrease of about 7 per cent. In this connection the factors of safety given in the last column are of interest. Of course, the factor of safety is the same for any one horizontal line. These factors of

*The figures in this table are determined by the slide rule, and are taken to the closest one hundred pounds.

safety become 5 at 20 per cent elongation for the square root formula, at about 29 per cent for the cube root formula, and at about 42 per cent for the fourth root formula.

With our rather conservative ideas as to the use of factors of safety, it looks as if the fourth root formula gave too low a factor of safety, and that if a weld were produced with 29 per cent elongation and 75,000 lb. ultimate strength, the factor of safety of 5 would not be unsafe, so that the cube root seems to be reasonable and to conform to general engineering ideas.

TABLE II

Per Cent Elongation by Bend Test	Ultimate Strength in Thousands of Lbs. per Sq. In. Over 45 up to 50	Over 50 up to 55	Over 55 up to 60	Over 60 up to 65	Over 65 up to 70	Over 70 up to 75	Over 75
5 to 7½	5,400	6,000	6,500	7,200	7,700	8,300	8,900
Over 7½ to 10	6,000	6,700	7,300	8,000	8,700	9,300	10,000
Over 10 to 12½	6,500	7,300	8,000	8,700	9,400	10,100	10,900
Over 12½ to 15	7,000	7,800	8,500	9,300	10,100	10,800	11,600
Over 15 to 17½	7,400	8,200	9,000	9,800	10,700	11,400	12,300
Over 17½ to 20	7,800	8,600	9,500	10,300	11,200	12,000	12,900
Over 20 to 22½	8,200	9,100	9,900	10,800	11,600	12,500	13,400
Over 22½ to 25	8,500	9,400	10,300	11,200	12,100	13,000	13,900

TABLE III

Per Cent Elongation by Bend Test		Ultimate Strength in Thousands of Lbs. per Sq. In. 45	50	55	60	65	70	75	Factor of Safety
5	√	4,450	4,970	5,500	5,950	6,450	6,950	7,500	10
	∛	5,000	5,600	6,100	6,700	7,200	7,800	8,300	9
	∜	5,300	5,950	6,500	7,100	7,600	8,250	8,850	8.5
7½	√	5,500	6,100	6,700	7,300	7,900	8,500	9,150	8.2
	∛	5,800	6,400	7,000	7,700	8,300	8,900	9,600	7.8
	∜	5,900	6,550	7,200	7,850	8,500	9,150	9,900	7.6
10	√	6,300	7,000	7,700	8,400	9,100	9,800	10,500	7.15
	∛	6,300	7,000	7,700	8,400	9,100	9,800	10,500	7.15
	∜	6,300	7,000	7,700	8,400	9,100	9,800	10,500	7.15
12½	√	7,100	7,800	8,600	9,400	10,200	11,000	11,800	6.35
	∛	6,800	7,600	8,300	9,000	9,800	10,500	11,300	6.65
	∜	6,700	7,400	8,150	8,900	9,650	10,400	11,200	6.7
15	√	7,900	8,800	9,700	10,600	11,500	12,300	13,200	5.7
	∛	7,200	8,000	8,800	9,600	10,400	11,100	12,000	6.25
	∜	7,100	7,800	8,600	9,400	10,200	11,000	11,800	6.35
17½	√	8,300	9,250	10,200	11,200	12,000	12,900	13,800	5.35
	∛	7,600	8,400	9,300	10,100	11,000	11,700	12,700	5.9
	∜	7,250	8,050	8,850	9,600	10,400	11,300	12,100	6.2
20	√	8,950	9,950	10,900	11,900	12,900	13,900	14,900	5.05
	∛	8,000	8,800	9,700	10,600	11,400	12,300	13,200	5.7
	∜	7,500	8,300	9,150	9,950	10,800	11,600	12,500	6.0
22½	√	9,250	10,500	11,500	12,600	13,600	14,700	15,800	4.75
	∛	8,300	9,200	10,100	11,000	11,800	12,800	13,700	5.5
	∜	7,700	8,600	9,400	10,600	11,200	12,000	12,900	5.8
25	√	10,000	11,100	12,200	13,600	14,300	15,500	16,600	4.5
	∛	8,600	9,500	10,500	11,400	12,400	13,200	14,200	5.3
	∜	7,950	8,800	9,700	10,600	11,500	12,300	13,200	5.7

The allowable working pressure in the Power Boiler Code is based on the minimum ultimate strength of the plate of 55,000 lb. per sq. in., the efficiency of the joint, and a factor of safety of 5, so that 11,000 lb. is the allowable working fiber stress.

In the Pressure Vessel Code, while the allowable fiber stresses are really based on a factor of safety of about 5 for riveted construction, a definite fiber stress of 10,000 lb. is permitted for plates less than 55,000 lb. ultimate strength, and 11,000 lb. for plates of 55,000 lb. or greater ultimate strength. So it might be feasible to simplify the table by adopting some plan similar to that in the Pressure Vessel Code, and Table II is submitted as showing what might be done in this direction.

Also, it may be unnecessary to make such small steps as Table I shows when the factors of safety are as large as they are, and when the tanks are tested to three times the working pressure. It is also true, with welding as it is with riveting, that no two joints are exactly the same, and that allowable commercial differences in welding rods will have some bearing on the physical properties of the weld metal. Therefore, some such form as Table II may be allowable.

In practice, proper procedure requires that the welders be tested. If the manufacturer had on file certified records of the welders, the inspector could check these records with the tanks that are being built, and by the use of the table could decide on the maximum allowable working pressure.

Table I gives higher values for welds than have ever before been presented for consideration, but no higher than have actually been used in practice with safe results in the cases on which the table is based. It is not believed that they can be used without proper procedure control, but it is felt that they are perfectly safe when such procedure control is followed in the construction of the tank.

It is rather interesting that it so happens that the allowable fiber stress at 50,000 lb. and 5 per cent elongation is 5600, the same as is used in the Pressure Vessel and Heating Boiler Codes.

At the values of tensile strength and elongation of cast iron, say 20,000 lb. and 0.2 per cent, the formula gives a fiber stress of 750 lb. As a common factor of safety for cast iron under shock is 20, the formula does not seem to be unreasonable at this extreme.

At the other end, we may take nickel steel that has been used for boilers. It has a tensile strength of 70,000 lb. and an elongation of 23 per cent (obtained by the tensile test and not by the bend test). The formula rating for this material is 12,900 lb., and with a factor of safety of 5 it would be allowed 14,000 lb. working stress. Therefore, it seems that the formula is within reason and does not violate good practice, even at the extremes.

Production Welding in the All-Steel Automobile Body Industry*

J. W. MEADOWCROFT†

FROM its inception into the automobile body industry 16 years ago, the Edw. G. Budd Manufacturing Company directly built and planned its future destiny around the welding industry. It is needless to say it has thrived exceptionally well on its original foundation. In the past 10 years many manufacturers have recognized the importance of all-steel construction in automobile body building, and a certain few have carried their thoughts further and have incorporated into their design the welding industry. This is not true in many cases where the steel construction has been found advantageous as both tubular and solid rivets are still favorably looked upon. A number of manufacturers apply welding methods in conjunction with their assemblies, and then further strengthen them by the addition of rivets. In the case of the latter construction our first question would be: "Is the rivet intermingled with the spot welds to prevent breakage of the welds" or "is the spot weld intermingled with the rivets to prevent the loosening of the rivet?" In many cases of this construction the above question has no application, as the rivet is really used as a means of properly locating pieces in their respective locations without the aid of a sizing fixture or jig, and later spot welded for its actual strength. The rivet or locating hole in this case is usually pierced in the stampings at the time of their pressing or formation, and assembled in accordance with these locaters at the time of assembly, first being riveted and followed by welding.

The first production of the all-steel automobile body some sixteen years ago was designed with welding as its main foundation of assembly, and from year to year the many changes of design have been originated with this same means of assembly in mind, until today our product may be termed an all-welded product, and rivets are used only at the insistance of the customer or at points where a sub-unit is attached to the main assembled unit and it is desirable to have a riveted joint in case of replacement. The sub-unit referred to in this case would be the doors of all models, the lids of coupes, roadsters, etc.

A comparison of the various methods of welding taken from our records show in 1914 that the per cent of the welding on each assembled body was:

Arc weld	5 per cent
Oxyacetylene weld	48 per cent
Spot weld	47 per cent

*To be presented at Fall Meeting, A. W. S., October, 1928.
†Assistant works manager, E. G. Budd, Manufacturing Co.

In 1928 we have the following comparison:

Arc weld	1.2 per cent
Oxyacetylene weld	30.3 per cent
Spot weld	68.5 per cent

Flash welding is considered as spot welding, being supervised by this department of the welding division.

The reduction of the percentage of arc welding in our case is due chiefly to the redesign of tapping blocks and small parts that the spot welding method might be used to greater advantages.

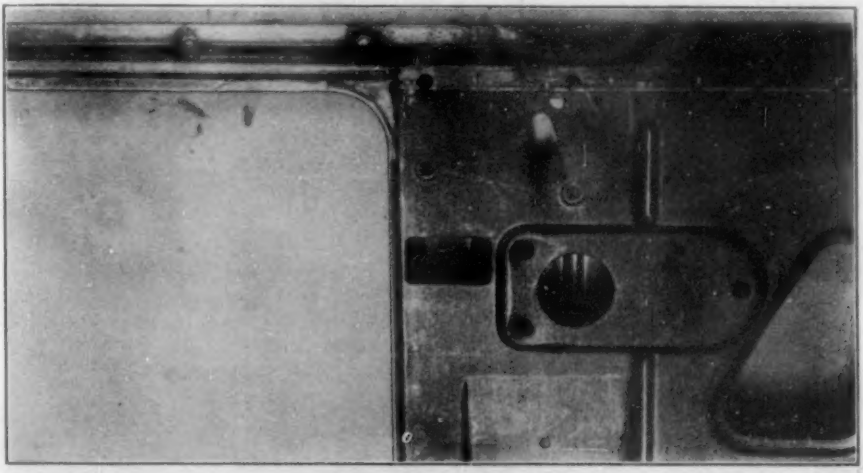


FIG. 1. METHOD OF ARC TACKING OUTSIDE DOOR PANEL TO ASSEMBLED INSIDE FRAME

The reduction of oxyacetylene welding is due chiefly to the flash welding of body parts that were ordinarily oxyacetylene welded and the adopting of the open joint at various points on the exterior of the body has also had considerable bearing on this reduction.

The greatest reduction in the use of the arc weld in our production is due to the change of welding methods, as indicated in Figs. 1 to 3.

Fig. 1 shows a method of arc tacking the outside door panel to the assembled inside frame of an all-steel automobile sedan door. In this case the arc tacks were unsightly and required considerable finish due to the occasional building up of the metal at points of contact, this building up being due to the continuous striking of a new arc.

Fig. 2 shows a method of spot welding developed especially for this operation. In this case the entire inner panel is energized while the single electrode or welding die shown affords the means of making the weld. This machine, known as the oblique spot welder, due to its indirect means of welding, is designed and built in our own plant and we feel positive in saying it is the only machine constructed entirely of welded joints throughout. The transformer is of Budd split type,

designed with special secondary voltage and the removal of four (4) bolts permits the removal of the secondary and primary coils. The flexible lead energizing the inside panel is of sufficient size and flexibility to carry the ampere load and permit the entire welding of the door with one handling. The flexible joint between the crossbar and flexible lead is water jacketed and of such construction that the weight of the unit makes a practically perfect contact. The entire welding operation in this machine is foot controlled. The result of this development is shown at Fig. A and B, Fig. 3, which illustrates the spot weld from the interior side and the clean surface on the outside panel.

Figs. 4 and 5 show the flash welding of the metal roof panel to the

FIG. 2. SPECIAL SPOT WELDING MACHINE DEVELOPED FOR TACKING OUTSIDE DOOR PANEL TO INSIDE FRAME

upper quarter panel of a standard constructed "all-steel" coupe body. The welding machine in Fig. 4 is of a standard design, manufactured and purchased with a thought to its flexibility. This type machine is used as standard in the flash welding of all two-piece cowls of earlier design, and all roof panel joints on the newer designed closed bodies, as shown in Fig. 5. The machine in this case is 125 kw. power driven and operates fully automatic.

It would be well to mention at this time that we will offer our version of the correct theory of the flash weld in a later paragraph, and while

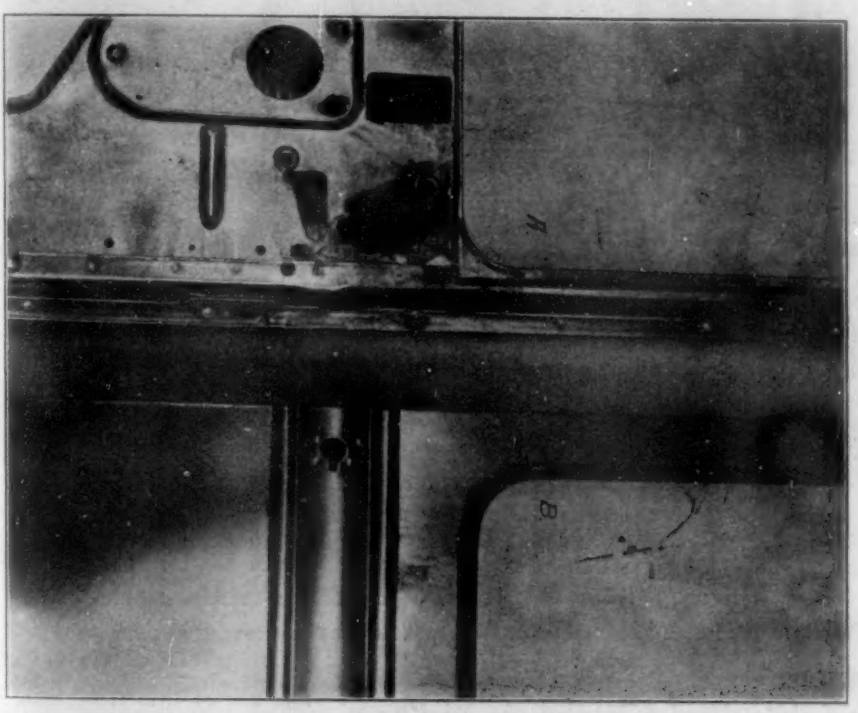


FIG. 3—SPOT WELD FROM INTERIOR SIDE, SHOWING CLEAN SURFACE

we do not claim anything revolutionary in our methods we contend that they are correct and all welding made to the contrary cannot give the maximum strength our theory produces.

Figs. 6 and 7 show a completed 48 in. seam flash welded tonneau and the interior view of the machine used on this production. The machine is of a standard design and manufactured with Budd sizing fixture. The machine is constructed of two individual welding units mounted on one bed plate. Each unit is equipped with one 200 kw. welding transformer and has a welding capacity of 70 in. of .043 standard auto body stock and operates individually by a 2 hp. motor. The total weights of the assembled machine is approximately 52,000 lb. The welding dies in this

case are of aluminum bronze due to the extreme pressures required to prevent slippage at the weld line, and the pressure developed across the face of the dies amounts to approximately 32 tons.

The following illustrations show a modern spot welding assembly line on the production of front ends for one of America's foremost producers of pleasure cars. The front end or unit in this case is standard

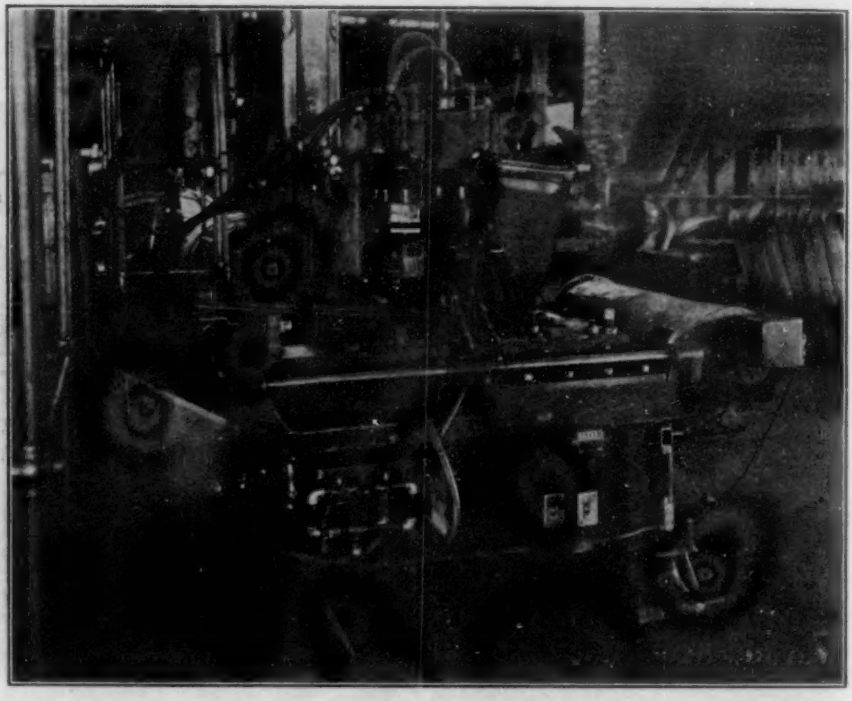


FIG. 4. FLASH WELDING MACHINE FOR WELDING TWO-PIECE COWLS AND ROOF PANEL JOINTS

on coupe, sedan, cabriolet and delivery cabs. The use of this front unit as a standard on four models of closed cars demands an exceptionally high production. In the production of a unit of this size many difficulties are encountered, and require careful consideration in laying out floor and production plans, viz:

1. The sequence of operation.
2. The production per welding machine.
3. The many positions of the piece during welding.
4. The jigging or locating of small parts to the assembled unit.
5. Floor space.
6. The handling of the unit in a manner that will keep it free from floor marks and other defects.
7. The failure of the operators to report each shift of operators.

All the above mentioned troublesome items have been items completely

eliminated by the application of our manually operated "welding conveyor" as this method of assembly by welding may be rightly termed and an even flow of quality production is assured. The most important operation of the entire assembly is the proper locating of the partly assembled outside shell to the interior strengthening or supporting frame work. This was accomplished very successfully by jigging the sub-units in an assembly fixture, and by means of especially designed loose toggle clamps, the unit could be assembled and removed from the jig by doing a minimum amount of operations, thus increasing the

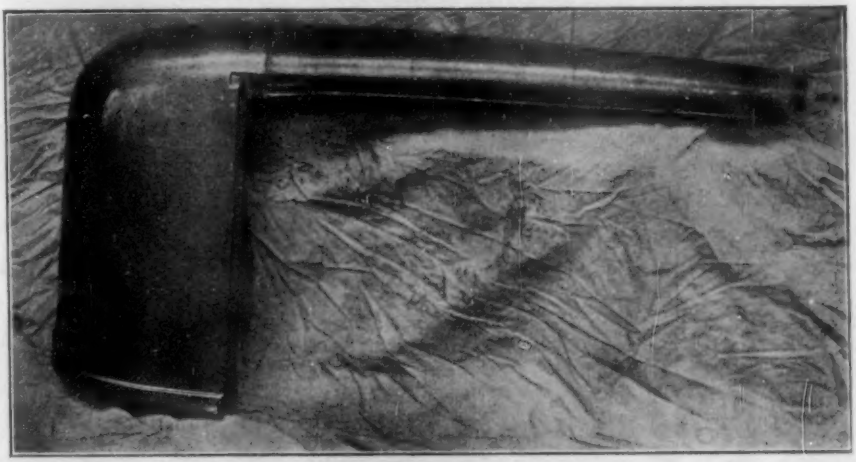


FIG. 5. FLASH WELDED ROOF PANEL

production of each assembly fixture and decreasing the amount of fixtures required. Fig. 8 shows the above mentioned assembly jig and the present method of joining the pieces together in a substantial manner for their removal from the jig. The toggle clamps have been discarded and a portable machine of a standard manufacture has replaced them. A few spots are placed at fixed points by each operator and the piece is removed. We have found a decided improvement in applying the portable spot welding machine in our line up as it has eliminated the manufacture of a large amount of toggle clamps along with the customary maintenance that they would ordinarily require. Another advantage to be found in this assembly method is that once the pieces have been properly aligned and tacked in place by means of the portable welding machine, no further attention is required as it will undoubtedly be in perfect alignment when completed.

Fig. 9 shows the unit passing through a number of operations on the high production side of the conveyor. The length of track on this production side being 296 feet and accommodating 19 standard upright welding machines. You will note space is provided between the welding machines allowing one or more pieces to hang in a neutral position. At this neutral space any small parts are assembled by jigs to the main unit by setters up located at necessary points.

Fig. 10 shows the flexibility of the hanger and the ease of operation as a single operator is handling the unit in this difficult position. This is characteristic of all other operations as no helpers are required. The trolleys shown support a shieve wheel or pulley permitting the unit to be placed at such different heights as the various operations may require.

Fig. 11 is a close view of an operation showing the method of operating the welding machine allowing the operator freedom of both hands, and we again call your attention to the ease of operation.

The welding operator along the conveyor is assigned to a certain task and his entire efforts can be localized to this task, in that he is not

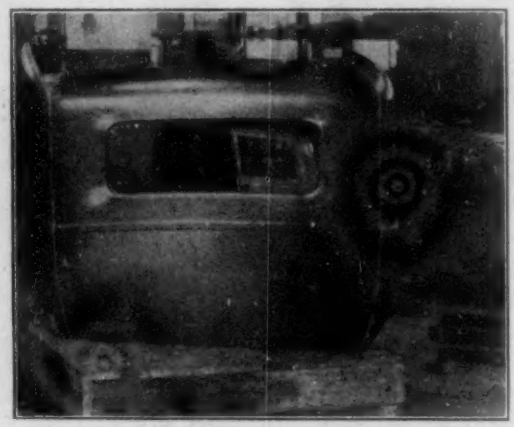


FIG. 6. COMPLETED FLASH WELDED TONNEAU

hampered by a helper moving the piece in directly opposite position than that desired by the operator, neither are his thoughts distracted by the following piece as ample space is provided between each machine to accommodate at least one piece in a neutral position. All obstacles encountered in the welding line are overcome in the following manner.

1. A sufficient amount of machines is provided on the conveyor to allow the splitting up or division of any operation by time study so that the amount of production expected from each operator is equalized.

2. The piece is carried along on hangers of great flexibility that permit any position to be attained. Where a desired position is not possible the machine is reconstructed to conform with this condition, the reconstruction being due entirely to the standardization of flexible equipment.

3. Space is provided, where necessary, between the welding machines where the setter up is located. He applies the jig and piece, and the

jig is returned by the operator. Enough jigs are provided in this case to make this method of assembly possible.

4. A minimum amount of floor space is required on high productions as no bank of material exists between operations.

5. You can readily picture the amount of handling and trucking required in a production of 110 pieces per hour. The condition of the outside finish after passing through 27 operations would be greatly impaired, and additional straightening and finishing would result.

6. Fig. 10 indicates, through the ceiling switch arrangement, that the line-up is of double construction, one side being lined up with a

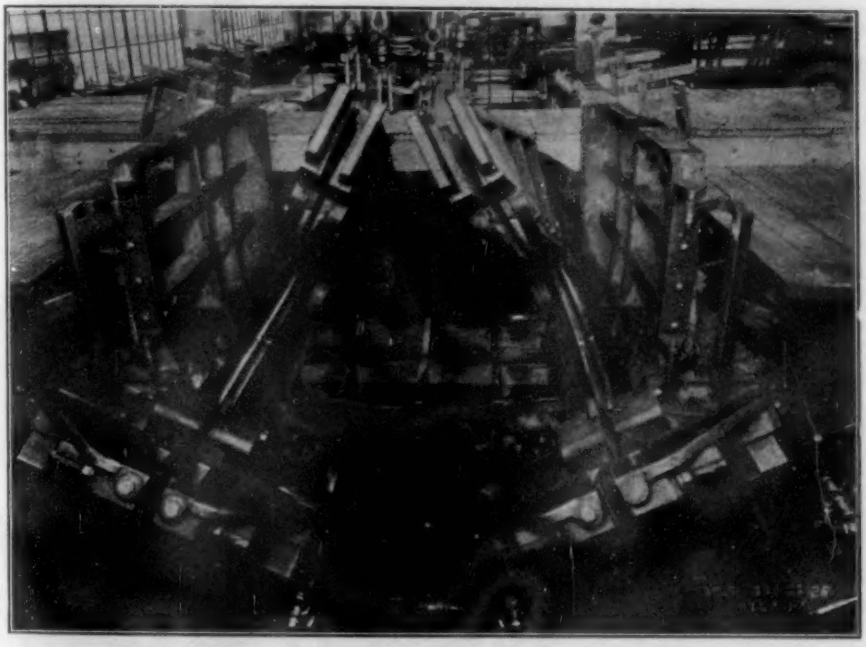


FIG. 7. INTERIOR VIEW OF MACHINE FOR FLASH WELDING TONNEAU

skeleton crew. From this crew experienced operators are drawn to keep the main line up in full operation at all times.

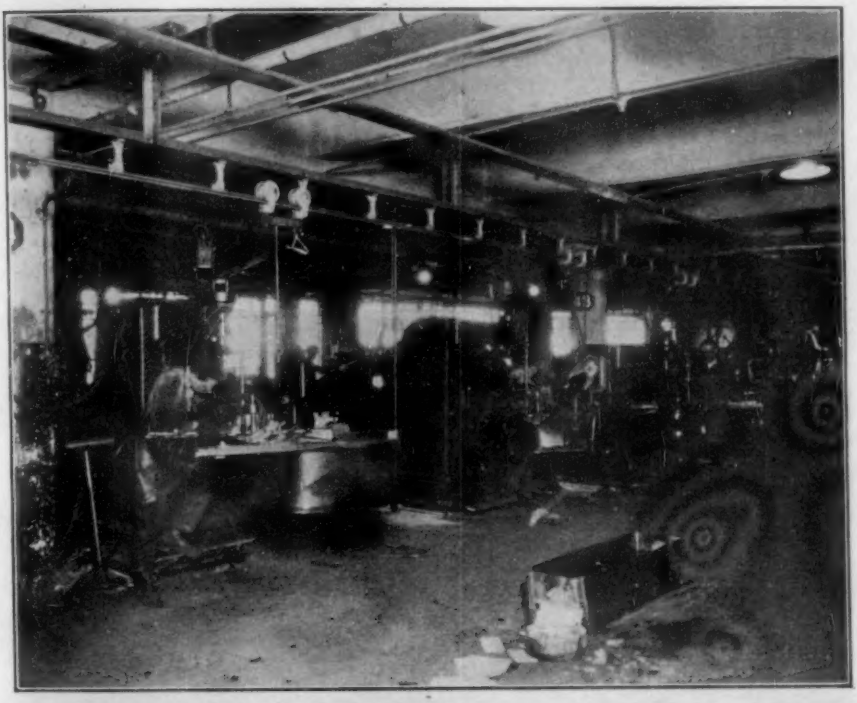
Fig. 12 shows by sketch a cross sectional view of two welding operations required in this line up. The outside panel is drilled in the windshield opening at a number of points allowing easy access to the inner or supporting post. The arc welding method is then used to attach the inner panel to the outside panel, and the filler rod used in phosphor bronze with reversed polarity. The opening is completely concealed at the finish of the weld and no distortion of the post is noticeable, as would be the case if oxyacetylene had been resorted to.

Fig. 13 (sketch) gives our theory of the correct method of flash welding and differs entirely from the old method of butt welding, in

that the metal involved is of greater thickness in the butt weld. The operation of the butt welder being to bring the edges of the metals to be welded together by means of an operating lever and then apply the electric current, which in this case is of a lower voltage than that of the flash welder. A small amount of flash exists in the first application of current after which the edges of the metals remain frozen due to the continuous pressure being applied by the operating lever. The current is applied continuously until the metal extending beyond the welding dies has reached a welding heat. At this point additional pressure is applied, the current released and the weld is made.

In the operation of the flash welder a perfect fit must exist between the upper and lower dies at all times while the lower dies, connected directly to the transformer terminals, must be kept in perfect alignment. This point is absolutely essential or the finish of the piece will greatly reduce the strength at the flash welded section. With the metal clamped in perfect alignment and extending beyond the dies ¼ in.

FIG. 8. SPECIAL DESIGN PORTABLE SPOT WELDING MACHINE DOES AWAY WITH TOGGLE CLAMPS



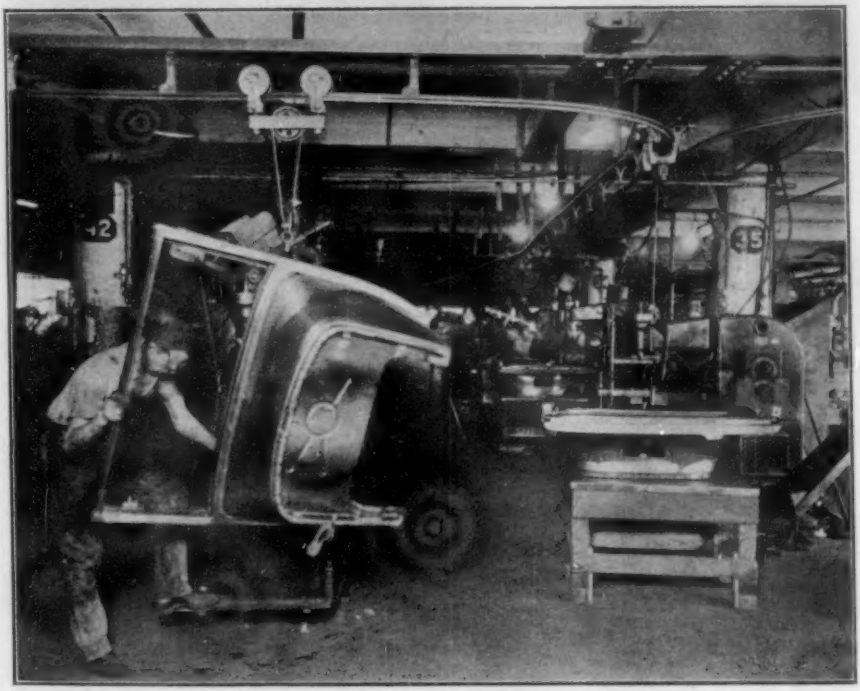


FIG. 9 (ABOVE). FIG. 10 (BELOW).

to 9/32 in. on each piece, as shown at illustration No. 13 (sketch) the current is applied before the edges of the metals come into contact, the voltage of the transformer being higher than that used in the butt welder. As the edges of the metal come into contact an arc is drawn setting up a decided flash. The speed of the machine and the voltage of the transformer secondary are timed to a point where the metal remaining is in a plastic state and ready for welding by the time the machine has reached the high point on the operating cam. At this point the power is cut off from the transformer and the actual welding operation is performed. Due to the amount of metal extend-

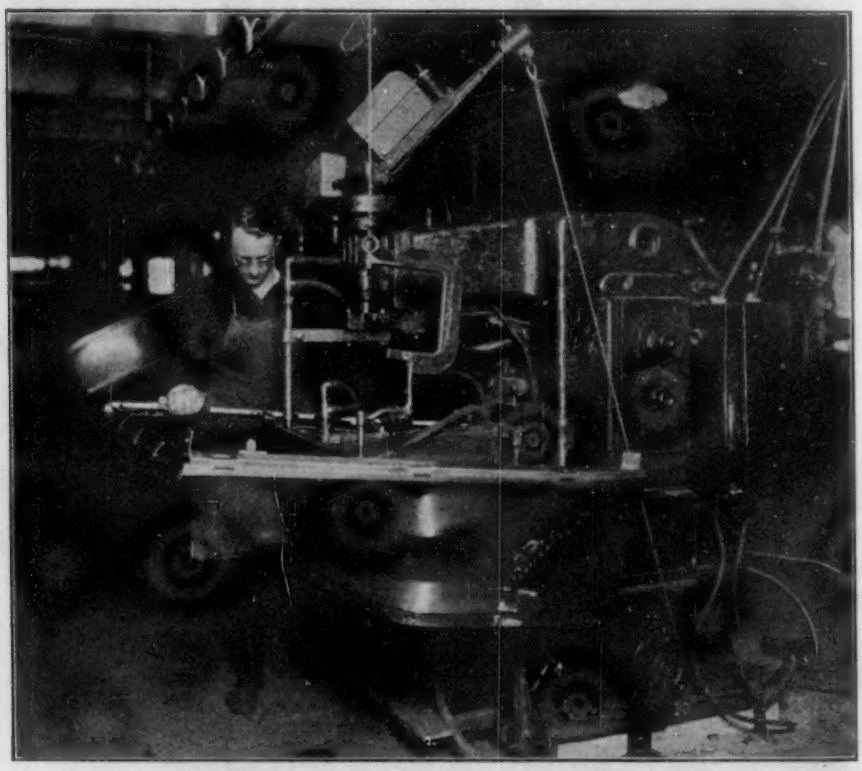


FIG. 11. CLOSE-UP VIEW OF WELDING OPERATION

ing beyond the welding dies, being the governing factor of the finished weld, it is absolutely necessary that the same amount of metal extend beyond both lower dies and care must be taken to follow this very closely otherwise, either piece may be at a welding heat while the opposite side will have been entirely flashed away. The result in this case will be exceptionally weak welds and in all probability it will not remain intact long enough to allow finishing.

We have attempted in this paper to show a completely new development in our oblique spot welder. While it is something new in a spot

FIG. 9 (ABOVE). FIG. 10 (BELOW).

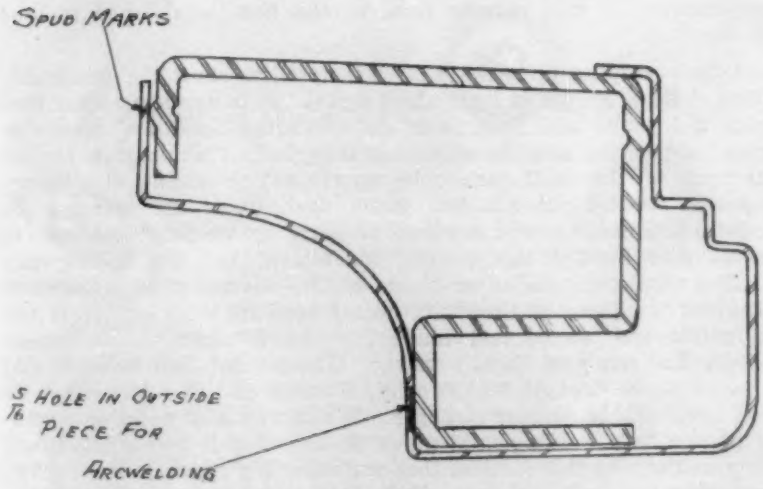


FIG. 12.—SKETCH SHOWING CROSS-SECTIONAL VIEW OF CONSTRUCTION AT WINDSHIELD OPENING, SHOWING TWO METHODS OF WELDING AT THIS SECTION

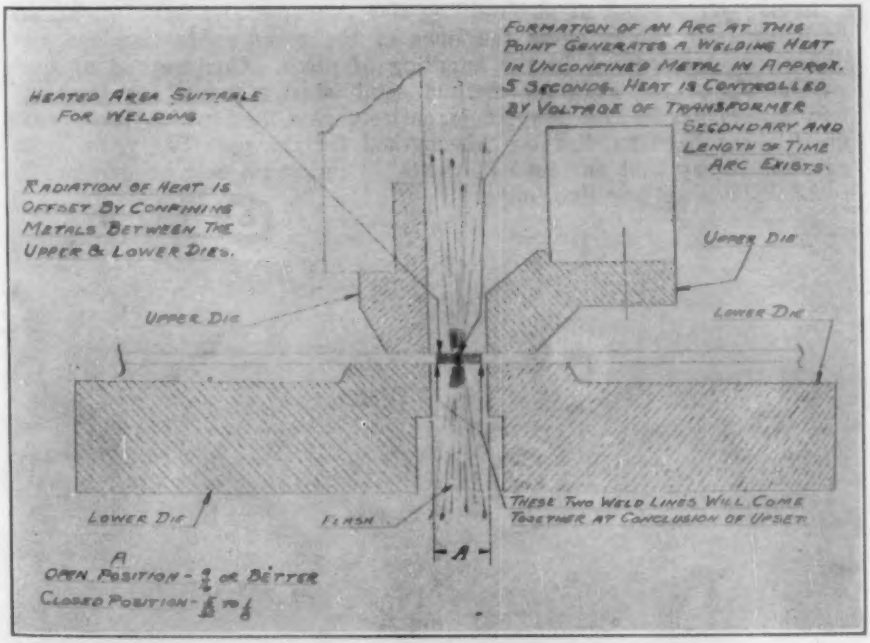

FORMATION OF AN ARC AT THIS POINT GENERATES A WELDING HEAT IN UNCONFINED METAL IN APPROX. 5 SECONDS. HEAT IS CONTROLLED BY VOLTAGE OF TRANSFORMER SECONDARY AND LENGTH OF TIME ARC EXISTS.
HEATED AREA SUITABLE FOR WELDING
RADIATION OF HEAT IS OFFSET BY CONFINING METALS BETWEEN THE UPPER & LOWER DIES.
UPPER DIE
UPPER DIE
LOWER DIE
LOWER DIE
FLASH
THESE TWO WELD LINES WILL COME TOGETHER AT CONCLUSION OF UPSET.
A
A
OPEN POSITION - 3/4 OR BETTER
CLOSED POSITION - 1/4 TO 1/8

FIG. 13. ILLUSTRATING THEORY OF CORRECT FLASH WELDING

welding machine it still reverts back to the first established method of spot welding.

In our flash welding notes we have attempted to show the possibility of welding difficult shapes in light sheet metal. It is needless to say that the welds are sound and free from defects after finishing, otherwise they would not be permissible on the outside shell of automobile bodies. The strength of the weld cannot be questioned providing the theory mentioned is strictly adhered to. Many flash welds are being made today where the metal is not confined properly by welding dies, and in most cases they answer the purpose for which they are meant very nicely. The usual test, placed on pieces of this character, is to hammer or flatten out the piece at the weld, but if sections were cut from the welded article and actual test made for tensile strength we would undoubtedly find many of them wanting. The correct flash weld should always be of equal strength to the original metal and in many cases we find it of considerably greater strength. While we claim nothing revolutionary in our flash welding method we do ask that if you contemplate doing any welding by this method that you carefully consider the following items that are real vital to good flash welding.

1st. The formation of the piece and the proper welding dies.
2nd. The voltage of the transformer in relation to the various thicknesses of stock.
3rd. The amount of metal allowed for flash off.
4th. The speed of the machine during the flash period.

In our explanation of our welding line conveyors we have attempted to bring your minds along the lines of the mass production and the difficulties encountered in the handling of piece. Our method of spot welding is of the ordinary method established many years ago, but our application in this respect is entirely new, and which large production has been handled by this method for the past two years it is needless to say that our first thoughts, in lining up new production, is to establish a welding line conveyor.

Running a Successful Job Welding Plant*

By JOSEPH S. OECHSLE†

METALWELD, INC., a Pennsylvania Corporation, as successor to a business started in 1920 by three brothers, with a cash capital of a few thousand dollars, today have one of the most successful welding organizations in the United States. Since 1920 the business has expanded rapidly and it has outgrown a plant that was erected in 1921. In the fall of 1924 the Corporation purchased a very valuable site, situated on Hunting Park Avenue at Twenty-sixth Street, of sufficient size to take care of future expansion, and on this plot of ground was erected the new plant. The new plant, shown herewith, is thoroughly modern in construction as well as attractive in appearance, and has approximately an acre of ground for future expansion. The plant faces on Hunting Park Avenue, having railroad siding facilities in the rear, and is thoroughly equipped carrying on a large welding and manufacturing business.

In order to help carry the overhead of our plant, it was necessary for the officers of the Corporation to find some article that could be manufactured and allow our welders to work on parts of this article at times when they were not busy on general welding, in order to keep a proper load factor. We considered various welded commodities, and at one time experimented a great deal on all-welded steel boilers for the heating trade; however, this was abandoned and we decided in 1922 to start building portable air compressors.

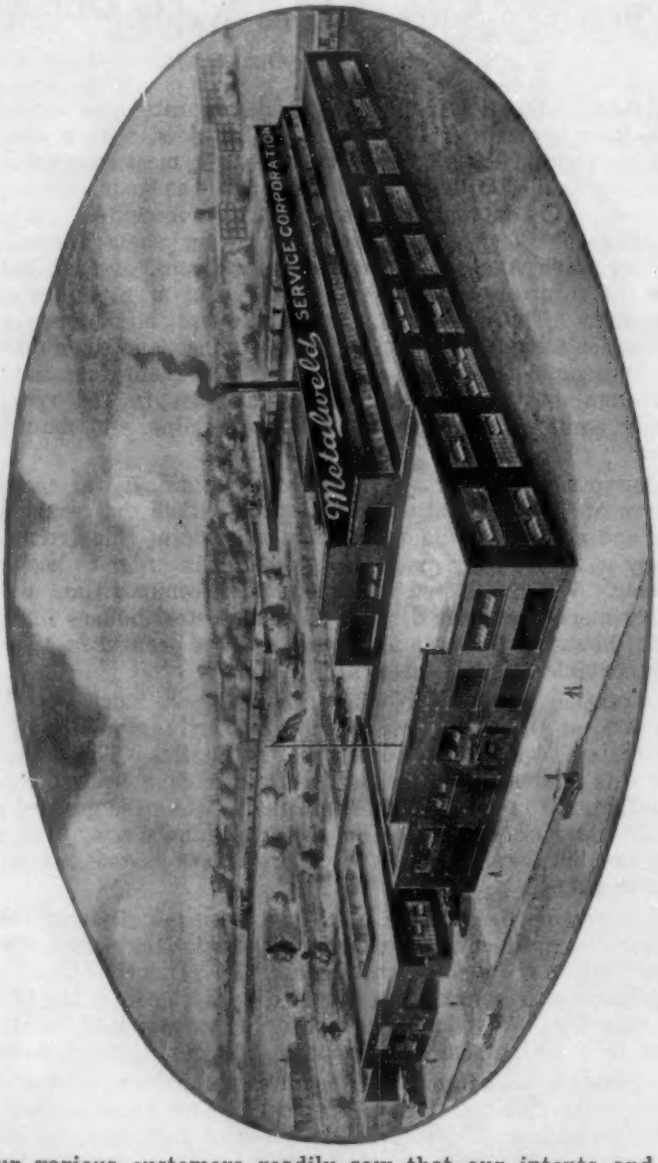
In cooperation with the Worthington Pump & Machinery Corp. we manufacture, at this plant, the Metalweld-Worthington line of portable air compressors, water pumps, and other specialties. The entire plant is used for this production work and the frames, canopies and other parts are manufactured in the welding department, while the general assembly of the air compressors is done on the mezzanine floors. The air compressors are built on an assembly line and are tested and painted in progressive stages.

The Corporation has dealers in all the principal cities of the United States, and the product is handled for export by the various Worthington export offices throughout the world. The product is a high quality one, and has been recognized as one of the leading lines in the air compressor industry. We take a great pride in our work of building these machines to a set standard of precision and quality workmanship.

At the time we went into the air compressor business most of the manufacturers were using cast steel frames, and we experimented a great deal with structural steel to take the place of cast steel for this work. The Corporation has been granted various patents on structural steel frame constructions, and in order to break down the resistance that was

*To be presented at Fall Meeting American Welding Society, October, 1929.
†President, Metalweld, Inc., Philadelphia, Pa.

at that time placed on welded products, it was necessary for us to guarantee each and every frame for the life of the machine against breakage due to normal use. This guarantee was a very broad one,



Bird's Eye View of Plant

and our various customers readily saw that our intents and purposes were well met in making such a broad assertion. We have never regretted this step, however, and we are certain that our arc welded steel frames are superior to any other.

As stated above, it is necessary for any large job welding shop to build some manufactured product in order to balance the load factor, and we have found that our manufacturing business has extended far beyond the scope of the welding business; due to the fact the welding business is more or less a localized business in which work can be handled within a radius of about 100 miles. However, with the air compressor business, having offices in all the principal cities of the United States and having foreign export department which handles the product throughout the world, it is possible for the plant to get on a large production schedule. The Corporation builds a full line of portable air compressors from 21 cu. ft. capacity to 350 cu. ft. capacity. The ideal lay-out of the plant enables us to handle this business very nicely.

We will not endeavor to go into the various engineering phases of the methods of welding, but will endeavor in this article to give you some idea as to how we attribute the success of our business. In order to do so

FIG. 2. ONE OF FLEET OF PORTABLE WELDING TRUCKS, USED FOR OUTSIDE REPAIR WORK

it will be necessary to explain that the Corporation has recognized and uses the three standard welding processes, namely, electric arc, thermit and oxyacetylene. With that view in mind, we have always maintained that there is a distinct use for each of these welding processes, and in order for a job welding shop to be successful, it is absolutely necessary that these three processes shall be used. For example, there are certain jobs that are best suited for reclamation by acetylene welding, such as machinery parts of iron castings, light sheet steel work, also the welding of bronze, brass and copper. Invariably you will find that the acetylene torch will make a better job than the electric arc on this class of work. There are other jobs, such as boiler plate work, which requires the electric arc process; and the other class that we refer to, namely, thermit welding, should be used on large crank shafts, rolls, large steel castings, stern frames of steam or motor ships, etc. We attribute the success of our welding corporation mainly due to the fact that all three of these processes are used extensively in our daily work.

To give you some idea as to how our plant is laid out, the front section of the building, which is approximately 150 ft. wide by 40 ft. deep, is composed of an upper and lower story. The lower story contains the

show room and sales department on one side while the opposite side is the stock room, where the various materials and instruments, welding wire, flux, etc., are stored. The second floor of this front building houses the executive offices. The plant is of the truss roof construction, having a crane way 40 ft. wide running up the center of the shop. This crane way is 35 ft. above the ground, and is equipped with a 15-ton Niles crane, which is capable of handling almost any size repair job. On each side of the crane way is a 20 ft. space, running along the sides, consisting of a ground floor, and directly above it the mezzanine floors.

On these floors various light welding and manufacturing is done. Opposite the main plant is the garage and service station and the main-

FIG. 3. FLOATING WELDING EQUIPMENT USED FOR WORK ON DELAWARE RIVER

tenance department for the various equipment, which is kept up-to-date at all times and in proper order.

Regarding the ground floor plan of the general plant; we have devoted the west side of the plant, under the mezzanine floor, a space approximately 160 ft. long by 20 ft. wide, to our oxyacetylene welding department, where small repair jobs are completed, such as crank cases of motors, small castings, gears, etc. There are also small box preheaters built and situated in this section, and connected up to a main gas line, which is of 6 in. diameter pipe extending from the meter, located in the stock room into the shop. A 12 in. diameter pipe supplies the gas to the meter. This oxyacetylene department is completely equipped, and at the rear of this floor is located the blacksmith forge shop, where one man is kept busy at all times reclaiming broken tools and redressing same, also making various forgings from steel.

The east side of the shop, under the mezzanine floor, which is similar in size to the west side, is devoted to electric arc welding. Electric arc welding machines are placed 20 ft. apart and are connected to switches that are attached to the upright columns of the plant. This department is laid out as follows: At the far end of the shop is the steel stock, where all of the plates, angles and structural steel necessary is stored. This plate stock is cut to size and goes to the lay-out table where it is fabricated and tacked strongly enough to enable it to be lifted by a monorail crane on to the various welding tables beyond, where electric welders work completely shielded from each other by portable screens. In laying

out this electric welding department in a progressive manner in this way, we find that we have been able to maintain a real production schedule, as there is no possibility of one man to interfere with another man's work. The ultra violet rays of the electric arc are very carefully shielded by these screens that are set up around each operator.

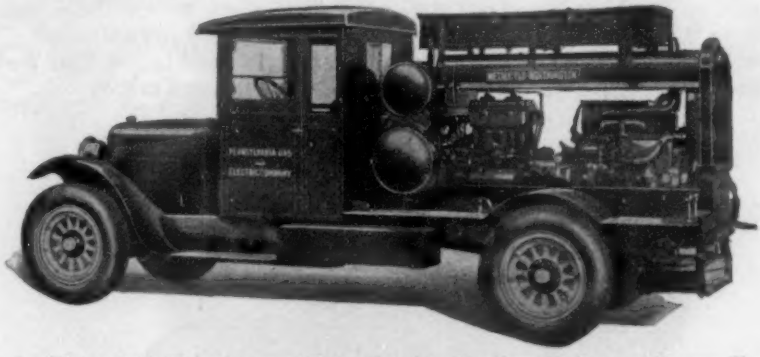


FIG. 4. METALWELD-WORTHINGTON PORTABLE AIR COMPRESSOR SOLD TO LARGE UTILITY COMPANIES

The center section of the plant, under the crane way, is devoted to the general repair work on motor trucks, clam shell buckets, boilers, tanks and heavy castings.

As stated above, there is a 12 in. gas main which enters from the street into the building, to which is connected three gigantic meters. From the meters are the 6 in. manifolds which run the entire length of the plant. From these 6 in. manifolds 3 in. and 4 in. manifolds lead off to the various large preheaters that are situated in this area. These large preheaters, on which we have various patents pending, were designed by the officers of the Corporation, and are ideal for the reclamation of large castings, such as gears, condenser shells, pulleys, fly wheels, etc. One preheater is 12 ft. by 12 ft. square, and is manifolded in such a way that it is possible with the controlling of valves to heat any section as required.

The entrance to the plant is between the main building and the maintenance building, and is a concrete runway 20 ft. wide. The doors of the plant are made exceptionally high in order that any size casting mounted on a motor truck or trailer can be readily hauled into the plant.

The 15 ton crane places the various castings over these gigantic preheaters, and they are chipped out preparatory to welding. The entire casting is then covered by a heavy sheet asbestos and is very slowly heated by this artificial gas.

We have found by observation that most of the small welding companies doing reclamation work on castings have been using the old method of preheating by charcoal, which is really obsolete. Charcoal was never much of a success in the welding of large, intricate castings that had already been machined, and the writer can cite hundreds of instances where welding received a "black eye" due to the fact that many inexperienced welders, with the use of charcoal for a heating agent,

caused some gigantic failures. The welding business has suffered in the past from various operators and small companies endeavoring to do work that was entirely too large for their plant equipment and knowledge. We have always claimed that to do successful welding it is necessary that thousands of dollars be invested into the business, and our contention has been borne out time after time when we see these various failures that have been welded by some small welding organization. The knowledge of welding is not acquired over night, and is one that is only gained after vast experience, which is sometimes very costly.

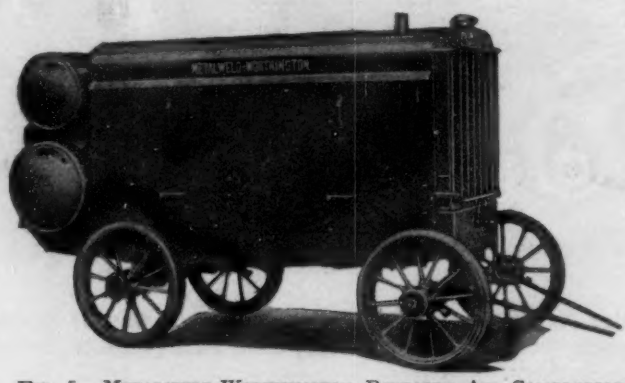


FIG. 5. METALWELD-WORTHINGTON PORTABLE AIR COMPRESSOR

We also have a special round preheater, which is 12 ft. in diameter, in which every one of the circular gas pipes are controlled by a valve. It is possible for us to weld all sizes of gears, pulleys or flywheels on this heater, due to the fact that the heat can be controlled every 6 in. in the radius of same, and it is possible to put more heat at the hub of the gear than at the rim or vice versa. This is a very intricate heater, and we believe it is the only one of its kind in the country today.

The center area, under the crane way, also contains our thermit welding department. We are very well set up to do large thermit welds on crank shafts, heavy castings, etc. A machined table, 25 ft. long, which is fully equipped with swivel "V" blocks large enough to take a shaft to 36 in. diameter, is used for this work. It was entirely built by the Corporation and it is possible with the table and "V" blocks to bolt down a broken crank shaft and maintain almost perfect alignment. Our thermit work has been very successful and the Corporation has to its credit about 25 steamships of which the stern frames, rudder posts or other parts were successfully thermit welded.

This description of the plant will give you a very good idea of the general arrangement, and we now discuss the qualifications of the welders that should be hired. We desire to make the statement that in our entire experience we have never hired a boy as an apprentice to do a man's work; in fact, we have never hired a man unless he has had excellent experience in welding. We found that it did not pay. Successful work is only possible when none but experienced welders are employed. Take our electric welding department, for instance; every welder that

is employed by the Corporation has to weld test specimens under the observation of an inspector of the United States Steamboat Inspection Department. These test specimens are then taken and various tests are made of them by reputable testing laboratories. It is then that the Department of Steamboat Inspection Service issue us a certificate showing the qualifications of each and every man. We find that this service is invaluable due to the fact that all of our men whom we employ are capable men, and it is possible for us to send them out on any kind

FIG. 6. LARGE 84 IN. DIAMETER GEAR BROKEN IN HALF

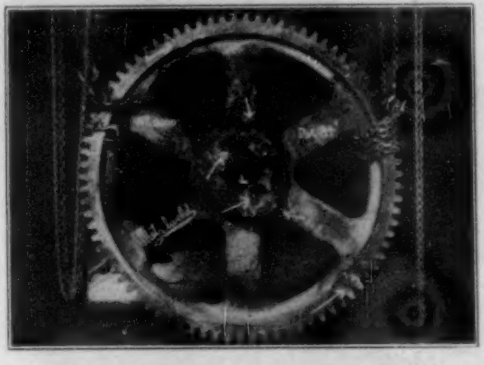


FIG. 7. VIEW OF GEAR COMPLETED (ARROWS SHOWING WELDS)

of boiler work when we know that the tests will be rigid, because they are qualified welders by the U. S. Government. This qualifying of our men also instills a good deal more pride in their work, and, after they once know they are certified welders, they are more particular and very careful as to how the work is executed. They realize, of course, that they cannot afford to make mistakes. We have found that in our entire welding career that our percentage of successful welds have been at least 95 per cent to 97 per cent. This is a very high average and we feel sure it is entirely due to the fact that the men are under constant supervision. We also try, wherever possible, to hire a man qualified as a combination welder; that is, one experienced in both electric arc and oxyacetylene welding. There is a varied amount of work in the job welding shop, and quite often a man will go out prepared to do an acetylene welding job when an electric arc job is really necessary.

The Corporation has a fleet of motor trucks with electric arc welding machines, oxyacetylene tanks, pneumatic air tools, air compressors, etc., and therefore when the operator goes out to do a welding job, if one method is not proper, it is a very simple matter for him to immediately do it with the other method.

Regarding the thermit welding end of the business, wish to state here that while this is one of the oldest welding processes, it is one of the least known, and every thermit welding job that is done by the Corporation is under the personal supervision of one of the Corporation's officers. We realize this work can not be trifled with as the reputation of the Corporation is at stake, and it would be very poor policy for us to send a man not thoroughly qualified to do a thermit welding job, especially on work on a steamship where hundreds of lives are depending entirely upon the rudder and stern frame of same.

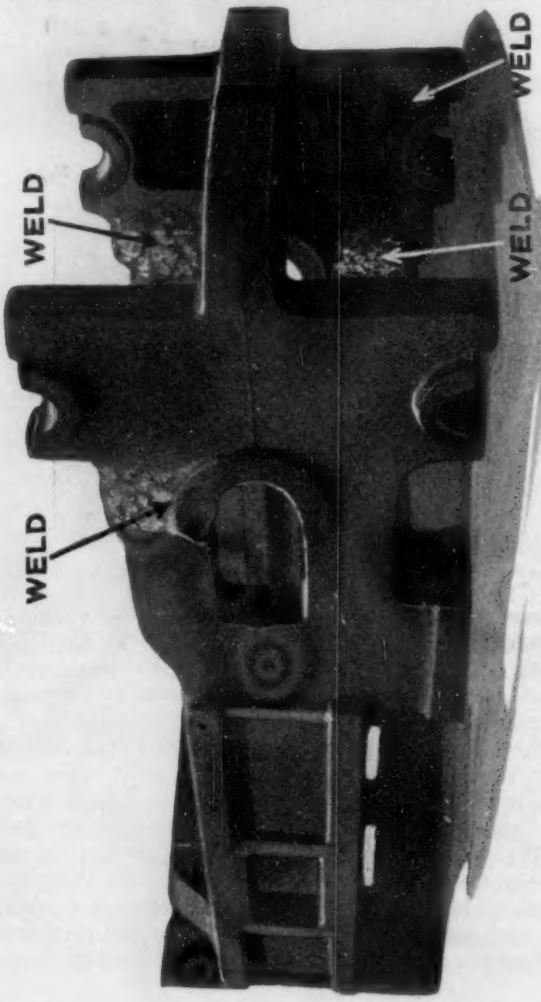


FIG. 8. LARGE PRESS FRAME HOUSING SHOWING WELDS, WEIGHT 16,000 LBS.

Some of the various steamships that have had welds made by the Corporation are the following:

The S. S. Eastern Dawn
The S. S. Kaduna
The S. S. Springfield
The S. S. West Inskep
The S. S. Persian
The S. S. Indian
The S. S. Hatteras
The S. S. City of Wilmington
and numerous others.

The Corporation is prepared to go anywhere in the country to do this work. Another phase of steamship work that we are often called upon to do is the reclamation of Diesel engine cylinder, pistons and various other parts, that are cracked or broken. We have special flux formulas and special grades of iron which we use in the welding of these special cylinder heads, and we have made a success of this particular work. We stress the possibilities of this work at this time because the motor ship is rapidly coming into its own, and the various Diesel engines that are in use are quite frequently in need of repair, due to the fact the pistons, cylinders, liners and various other castings often break due to excessive heat. We make a specialty of this particular work, and believe we are the only ones in the country that have ever done any research work along these lines. Some of the various motor ships on which we have welded heads, cylinders, pistons, etc. are as follows: Motor Ship California, Motor Ship Hamlet, and various others.

The Corporation since its beginning has also saved thousands of dollars in the compounding of our own special fluxes that are used in our welding work. We do not purchase flux of any kind, all of it being compounded in our own stock department. We have had excellent results and this saving, while it would not be practicable for the small welder to experiment with fluxes, really pays. We also make our own aluminum solder, which also effects quite a large saving, due to the fact that the various solders on the market are quite expensive.

Regarding the administration work, we will now deal with the routing of shop cards, and the bookkeeping necessary to properly carry on a welding organization. There is a good deal of bookkeeping attached to it and our records are very complete in this respect. A welding job coming into the plant would be immediately written out on a printed form in triplicate, one copy of this form would go to the office and the other two copies to the shop Superintendent, and to one of these copies all of the various material and labor costs are listed thereon. When the work is completed this card then returns to the office and the various prices of acetylene, oxygen, electricity, flux, welding wire and other parts are accurately figured on this card. The overhead and profit is then added, and the customer's billing is based entirely upon the labor and materials that go into the job plus the overhead and profit. In other words, we do not charge for what we feel the job is worth, but only charge a legitimate profit over the actual cost. This is one of the hardest things

in the welding industry to do, to properly charge for welding work. Quite often the customer demands an estimate before the welder is allowed to proceed with the work. As you well know, quite often, taking a casting for instance, when the casting is in the preheater and brought up to a dull red heat, other cracks may show under the heat, and it is necessary for the welder at that time to continue on until the casting is restored to its proper condition. In this case the original estimate has been given to the customer, and we find it very hard to go back to him and ask him for more money to cover the additional work. We feel certain that wherever possible it is recommended not to quote the customer a set price because of these conditions that quite often arise. However, cheap competition has brought this condition about and it is rather hard to get the jobs on a cost plus basis.

We have found that the welding industry as stated before has suffered tremendously by these small welding shops, and the writer is often amused when traveling about, when he observes a sign hanging over a garage where the following inscription is printed thereon "Automobile Repairing and Welding." It seems the average welding shop is just a tacked on addition to another business. You can readily see that the proper thought and engineering is not given to a job when it goes to a shop of this kind. The customer, however, is often to blame because he does not consider the intricate work and the engineering that is necessary to properly reclaim some jobs, and they underestimate the possibilities of failure. They therefore abide by the lowest price, and invariably you will find in these small shops the operator has wasted much time and money and is unsuccessful in getting a satisfactory repair, and the customer is discouraged and his mind is prejudiced against welding, and the consequences are the welding industry suffers as a whole. We have that particularly true in the welding of pressure vessels. Welding of pressure vessels should not be attempted by anyone not conversant with the laws of the country regarding same. Every day there are listings of explosions that have taken place in boilers, and in 75 per cent of the cases you will find upon investigation that they were caused due to the fact that some man did not understand his business and tackled a job that was entirely too big for him. This condition is rapidly clearing up however, because welding has taken such tremendous strides in the last few years that the average man can not afford to remain prejudiced against it for any long length of time.

Welding has made enormous strides and will continue to do so, but it is necessary for the welding companies to spend enough money to go into the business right in order to be properly recognized. You only get out of a business what you put into it. Due to the fact that we have spent great sums of money to bring our equipment and plant up to date, we feel that is really the main reason for our success, and we trust in closing that some of the ideas that we have put forth in this article, will help some other welding shop proprietor to realize just what conditions the welding is facing today; and in that way, by him bettering his own condition, the welding business will be a great deal more thought of than it was in the past, and we can look for a successful era in the future built up by these pioneers who went into the game when it was in its infancy.

Metal Arc Welding*

A study by H. Dustin, Professor and Director of Materials Testing Laboratory, University of Brussels. Originally published in the December, 1926, issue of "Revue Universelle Des Mines," Liege, Belgium, and now translated for the Journal of the American Welding Society by F. T. Llewellyn.

INTRODUCTION

OUR new testing laboratories, opened on the 20th of November, 1924, were ready by the beginning of 1925 to undertake such work as did not call for very special equipment.

From that time on we were able to carry out the suggestion of an industrial group that we prosecute a systematic investigation of arc welding, for the purpose of establishing a rational basis for the design of welded connections, with special reference to joints for framed structures.

After several weeks of clerical preparation, during which we did some miscellaneous testing in order to become familiar with the subject, we were in position to lay out a satisfactory program.

Before attempting the study of complete welded joints, it appeared desirable to secure more accurate knowledge of the weld itself, considered without reference to the members to be joined. The investigation therefore was divided into two parts:

1. A study of the metallurgical and mechanical characteristics of deposited weld metal, including its effect on the base metal.
2. A systematic study of welded joints.

By the spring of 1926 the first part of our work had progressed far enough to give results that would assist in the study of the joints themselves. We will here summarize such results as had been obtained up to that time.

I. Scope

Our subject is the study of welding by the electric metal arc process.

After examining 14 samples of electrode welding wire and the metal deposited therefrom, we selected for study three typical grades of wire which will be designated respectively by the symbols B, T, and N. All three wires make a deposit of mild steel, and are thus suited for making structural joints, the ultimate aim of our study. The scope of the investigation was determined in these respects by May, 1925.

**Translator's Note.* The paper captioned above deals with only the first of the two parts into which the author divided his investigation, namely the weld metal. The second part, dealing with the joints themselves, has been summarized by Professor Dustin in a paper which received second place in the Lincoln Arc Welding Prize Contest for 1927. This paper will doubtless be published in America before long. Both studies consider only *coated* electrode results.

In addition to the tables, here expressed in American units, the original paper was illustrated by 22 half-tones of testing equipment, specimens, charts, and metallographs of 100 to 300 diameters.

II. Nature of the Wires and the Metal Deposited Therefrom

Wire B is of a covered type. It is one of the best wires on the market, but somewhat costly. It deposits metal that is remarkably clean and very strong. Its maximum tensile strength per square inch (Z) is 71.1 kips. (A kip is 1000 lb.)

Wire T is one of the best coated electrodes, less costly than B and widely used in France. It also deposits a clean weld whose Z is 56.9 kips, which, while lower than that of B, is sufficient for most purposes.

Wire N is inexpensive. It has a light refractory coating. It deposits a weld whose Z almost equals that of T, but the metal is much less homogeneous.

All three electrodes are composed of mild steel wire of good standard quality. It is known from many analyses that there is no direct relation between the composition of the wire and that of the weld. In an arc the combustible elements of steel are partially consumed and, in the case of wires of the kind we studied, the composition of the deposited metal is correspondingly changed. Manganese is affected but little, silicon disappears almost completely, phosphorus is somewhat and sulphur greatly reduced, while carbon remains at from 0.10 to 0.14 per cent.

In the case of certain other electrodes, especially when made of bare wire, a disappearance of manganese, retention of sulphur, and reduction of carbon to less than 0.05 per cent, have been observed.

Regardless of its flux coating or covering, welding wire normally deposits a soft steel that is purer than its source. The effect of coating on the wire is important, for it determines the value and characteristics of the deposited metal. Its functions are three-fold:

1. To combine with the oxides in the base metal.
2. To protect the molten or white-hot metal with a deoxidizing slag.
3. To serve as a vehicle for the introduction into the weld of special elements (carbon, nickel, manganese, chrome, etc.) in case it is desired to modify properties.

By providing a suitable coating we can actually deposit a steel of any predetermined composition, even stainless or high-speed tool steel.

Returning to our three typical electrodes: Wire B is electroplated with 1.25 per cent of nickel, and covered with a braided asbestos fabric which confines the slagging elements in a thick coat. Wire T contains no nickel. Its coating is thick enough to dispense with a supporting fabric. Wire N has only a thin coating. The composition of the coatings is a trade secret. Some typical compositions have been published, e.g. on page 292 of the June, 1925, issue of "Revue de Metallurgie".

Wires B and T furnish an abundance of thick slag that adequately covers molten and base metal, but they are somewhat difficult for an inexperienced welder to handle. Wire N on the other hand produces a smaller amount of quite fluid slag that is easily blown away by the arc. It is readily operated and permits quick work, but the resulting deoxidation is somewhat scanty.

The first two wires are to be recommended for strength joints. The third is suitable for common repair work.

With such differences in the constitution of these wires considered as types, let us now compare resulting differences in the structure and behavior of the metal deposited.

III. Slag Inclusions and Porosity

It has been broadly claimed that weld metal abounds with slag inclusions and is porous with blow-holes, and that its strength is therefore unreliable.

If inspection is only superficial, the ruptured section of a weld does often present an appearance not calculated to inspire confidence. There are marked variations in grain, brightness, and color. This is true, not only when comparing different samples, but even within the compass of the same section. This will be referred to later. We have been unable to establish any relation between the appearance of ruptured surfaces and the result of physical tests. For this reason it seemed logical to begin the study of weld metal with a systematic examination for inclusions and porosity.

In the course of all our tests we cut sections through numerous specimens, welded portions, and complete joints. In addition, before definitely settling upon a program of physical tests, and with the idea of being able to form preliminary assumptions from the characteristics of deposited metal, we proceeded as follows:

Using 14 different kinds of wire, we built up pads about 1.50 in. square by depositing successive layers of weld metal on a suitable backing. These pads were then sawed out so as to permit us readily and thoroughly to explore their interior in all directions. Microscopic examination of 200 polished sections, in pads, specimens, and joints, led to the following conclusions:

The cleanness of deposited metal depends on its composition and on the quality of the welding wire. Special grades of steel, deposited by the welding process, generally appear to include more slag than the mild grades most frequently employed for joints; but it should be noted that deposits from special alloy wires have not yet been subjected to research as fully as have those intended for standard construction.

The first conclusion is self-evident. The quality of a welding wire is indicated by the cleanness of the metal deposited by it.

If we restrict ourselves to good grades of wire, such as are used in the class of joints we are specially interested in, we find that, taken as a whole, weld metal is exceedingly clean.

It is necessary to distinguish between minor and major inclusions. We will limit the term "major inclusion" to one visible to the naked eye, i.e. having a size of say one hundredth of an inch or more. In the metals we are studying an inclusion four to eight hundredths of an inch in extent is seldom found.

Minor inclusions occur, sometimes uniformly distributed, sometimes localized in fine bands very similar to those observed in forged or rolled commercial steel. These bands are located in plan in the successive layers

of a weld. Compared with grades of steel used in standard construction, metal of this kind can be classed as clean, or indeed very clean. On a number of joint-sections we personally detected cases, in the zone of union of base with weld metal, marked by a definite reduction in inclusions. (When observing a polished section with the naked eye the two metals are distinguishable by a notable difference in brightness, especially under oblique light).

In the case of special wires, such as B, inclusions are not only rare and very fine, but they are uniformly distributed and show little tendency to localize in weak spots. As regards amount and distribution, microscopic inclusions resulting from wire T are similar to those of B. Wire N produces inclusions that are noticeably larger and more localized. However, these differences are insufficient to account for the large discrepancies found in physical tests, particularly in impact tests.

From the standpoint of frequency and extent, but more especially as regards form and structure, the occurrence of major inclusions is much more indicative of the wire used. When examined under a suitable magnification (300 diameters), in addition to typical outline there appears granulation and crystalline structure of diverse color that varies tremendously in different wire-metals. There is no doubt that wires differ principally in the composition and amount of their coating, which furnishes the slag and consequently affects inclusions.

Major inclusions are in truth an indelible signature engraved by the wire on the weld.

In the case of wire T, and still more wire B, major inclusions are rare. Such as occur take the form of droplets of slag imprisoned in the fused metal. Insofar as inclusions of this kind are small in size and few in number, we need not be alarmed by them. They simply mean there is an insignificant reduction in net section available for strength purposes.

In the case of wire N, however, the matter is of more moment. Along with droplets of slag, there are found dirty lines in the form of arcs of circles more or less developed and of very variable radius. Close inspection indicates that the weld contains a number of globules of steel partially surrounded by a dirty envelope, probably of oxide, which separates them from the adjacent metal to which they are actually united only at intervals. Their appearance is very similar to what foundry men call "cold shuts." Wire N conceals within its bosom the beginnings of disaster. This is confirmed by the results of mechanical test.

So much for the weld taken as a whole. Passing on to the contour of the weld we find two distinct zones which provide notable rendezvous where inclusions have a great tendency to foregather:

1. The unimportant exterior surface of the weld discloses a layer full of inclusions with some blow-holes, whose size does not much exceed 0.04 inch. This layer is always surplus metal, and is not considered in calculations for strength. It is sometimes ground off.

2. The transition zone. The zone uniting weld to base metal occasionally discloses inclusions when the rest of the weld is free from them. Sometimes these inclusions are fairly abundant and combine to form a dark line that is visible when the section is polished. Sometimes also there is found a large flat inclusion.

This localization of inclusions, which can be noted even with the best wires, warrants our attention, for it tends to create in the joint a section of reduced strength. Welders are fully aware of this weaker zone, and make allowance for it. In a survey of the details of standard joints in several existing structures, the contact surface was found to be always greater than the net section of either base or weld metal. The ratio is frequently 1½ to 1, which fully allows for possible inclusions. In our tests rupture at the transition zone was rare.

Major inclusions in the transition zone, which are apparently accepted by the welding industry as a necessary evil, can, we think, be avoided by proper technique.

In any event, the mere fact that such inclusions may exist, and that it is practically impossible for us to know whether they do except by destructive test, makes it advisable to provide a contact surface that will be large enough to compensate for their possible presence. This is a prime factor that we shall have to take into consideration in the standardization of joint-design.

IV. Microstructure of the Weld

In looking over treatises on welding one is struck by a vagueness and lack of precision in many of the published micrographs. In our opinion the cause for this should be sought, not in lack of skill on the part of microscopists, but in the fact that weld metal does not respond to the same reagents as are usually employed in the examination of steel.

After several experiments we adopted the Portevin reagent in our examinations. It is merely a solution of 3 per cent fuming nitric acid in ethyl alcohol. This reagent is very uniform and rapid, and is applied by simply immersing a sample in it for from 2 to 10 seconds. It has the disadvantage of making a polished surface very corrodible in air. After careful washing and drying, treated samples are noticeably changed, within a few days in free air, and within a few weeks even if kept in a dessicator.

If we cut and etch a section through a welded joint, and examine it under a reasonable magnification (100 diameters is sufficient), extending between the base metal and the outside surface we find a series of zones clearly differentiated as to structure.

Regardless of grade of wire or welding conditions, these zones occur always in the same sequence and with constant characteristics. Even their relative importance varies but little in different samples. It might be concluded that these zones are controlled by physical factors inherent in the process of arc welding, and that is our belief. Reference is made, of course, to mild steel welds. We find:

(a) A transition zone at the contact surface of weld and base metal.
(b) A typical structure in the body of the weld.
(c) A dendritic or branched structure in the outside layer of the weld.

Transition Zone. The base metal, which is usually mild structural steel, displays regular ferrite of larger or smaller grain-size, in contour

mostly polygonal and marked with a fine definite outline. On nearing the contact surface the grain becomes gradually finer.

This reduction in grain-size occurs only in a few layers whose total thickness does not exceed 0.004 to 0.008 in. in the case of the mild grades of steel used in structural and boiler work. It extends to a greater thickness (perhaps double) in the case of higher carbon steels, such as rail steel, which are more responsive to the effect of heat.

This grain reduction near the contact surface is readily explained. The heat of the arc melts the surface of the base metal, but as soon as the electrode moves away the thermal conductivity of the base metal, combined with an inflow of air, causes a sudden cooling with ensuing solidification in fine crystals and actual quench-effect. When the electrode deposits additional metal it produces a rapid reheating followed by somewhat slower cooling. This is repeated on its third passage, and so on. But the reheating is too rapid to again form large grain in the mild steel base metal. That would require a temperature of 1000 deg. C. and a duration of several minutes, conditions that never obtain in welding.

The zone in which there is interpenetration of the two metals is equally thin, and includes only layers of crystal (usually 5 to 7 in number) with a total thickness of from 0.008 to 0.012 inch.

We find in the weld some isolated crystals stolen by the arc from the base metal, but never any isolated weld crystals in the base metal. While exploring the weld we meet certain other layers of crystal having the regular appearance of ferrite, and then almost at once the aspect changes and we reach the zone of typical structure.

The transition area may be readily shown by either of two methods. In the union of a mild steel deposit with mild steel base metal, the Portevin process may be used to show that atmospheric oxidation acts very differently on the two metals. The obscure weld crystals appear dark by the side of crystals that are still unchanged. In uniting a mild steel deposit with hard steel base metal (or the reverse), the interpenetration of the elements is followed by a progressive disappearance of pearlite. Although the transition is rapid it is nevertheless quite gradual.

What material constitutes the thin layer separating the zone of interpenetration from the typical zone? We believe it is pure welding wire that has crystallized in small grains in the form of typical ferrite. This conclusion seems justified by:

1. The action of etching reagents.
2. The presence in the body of the weld of small isolated nuclei having the structure of typical ferrite.

While the entire transition zone is very thin, its existence may be confirmed also by mechanical test. The Shore scleroscope enables us to evaluate variations in the hardness of metal at points very close together. By plotting a system of indentations suitably located, we can readily show that the belt of separation between indentations that denote the respective hardness of base and weld metal proper is less than 0.04 in. wide.

Typical Structure. As a whole, the mild steel deposited from all of the three wires studied forms a structure marked by characteristics that distinguish it from mild rolled steel. The feature that first strikes one is the "hatched" appearance of the typical structure in a metallograph. The entire etched surface appears to be covered with short grooves or hatch-marks, straight and deep as if made by an engraver's tool. The contour of ferrite cells cannot be traced. Most of these contours do not close, and the grains seem to be welded together on one of several faces. The hatch-marks (1 or 2, but rarely 3 per grain) seldom cross the cellular contours, and are generally confined to a single grain.

This typical structure is not an illusion resulting from the difficulties of metallography. By prolonging the etch, by varying and alternating reagents, the pattern is explored deeper and deeper, but no new element is developed. (Compare also the result of heat treatment cited below).

Hatch-marks have been noted previously by several observers, and given various interpretations, at times quite at random. Most frequently they are described as being needles of iron nitride, sometimes as crystalline flakes seen in cross-section. In our opinion they are merely lines of cleavage, or fault-edges, comparable in size to the space between adjacent grains. That is what they look like under slanting light when magnified 1000 diameters.

Whatever welding wire is used, this typical structure is always evident. But its stability varies exceedingly with different wires. For example:

Metal B. When heated to 900 deg. C., or higher, this structure disappears and is replaced by ferrite, of fine or very fine grain according to the temperature reached and the speed of cooling. In general each more or less vaguely defined grain turns into several smaller new grains. If quenched in water we find a mixture of troosite and martensite varying in proportions according to its temperature at time of quenching.

Metal T. When heated to 900 deg. C. and cooled in air, the typical structure remains unchanged. To cause disappearance it must be heated to 1000 deg. and allowed to cool slowly in the furnace. This treatment gives fine-grained ferrite. If quenched in water at 900 deg. one secures ferrite in small tangled grains, with a little badly formed pearlite interlaced in the joints. By drawing back after quenching the typical structure is restored.

Metal N. Even by maintenance for two hours at 1000 deg. C., and cooling very slowly, the structure is not destroyed. The hatch-marks merely become a little less numerous. If quenched and drawn back this metal behaves like T.

It is evidently useless to try to anneal material welded with wires T or N. Treatment to which weld metal would respond would be dangerous for the base metal. Can we expect any practical gain by annealing welds made with wire B?

The physical factors most affected by heat treatment are those of impact and hardness. We find that a treatment sufficient to change the typical structure of the weld increases resilience only about 12 to 15 per cent, and reduces hardness only about 10 to 12 per cent. That is not enough to justify the inconvenience of an annealing process.

Dendritic or Cast Structure. This occurs in the last layers of deposited metal. The dendrites are oriented more or less perpendicular to the out-

side surface. The thickness of this structure varies with the extent of the weld, and seems to approach a maximum of 0.20 to 0.24 in. which is reached when the depth of weld reaches 0.50 to 0.60 in.

There is progressive transformation from dendritic to typical structure. Since this transformation extends to some depth in metal already solid, it may be attributable to heat effect developed in the process of welding, and this is confirmed by experience. If heated to 900 deg. C., dendritic changes to typical structure.

What is the influence of this dendritic structure on the resistance of welded joints? It is hard to say. It generally occupies only a small proportion of the section of a joint. It exists principally in the excess material deposited. In machined specimens it is almost entirely removed.

However, a number of ruptured sections were observed in which it was very noticeable, but its presence was accompanied by no striking anomaly in test results. We may assume that its influence is small and perhaps negligible.

Abnormal Structures. Sometimes, notably in the case of metal B, we found small cores of ferrite (12 to 20 grains) in the typical structure. More frequently, especially when using wires T and N, we found isolated dendrites in the typical structure, or a dendrite penetrating it more or less deeply. We have not discovered the cause of these anomalies.

General Observation. All of the three wires that we selected as types deposit metal whose carbon content is of some consequence. Analysis shows 0.10 to 0.14 per cent. Its strength also corresponds to a considerable carbon content. The effect of heat treatment confirms this. We have seen that by quenching metal B may attain a quite clear martensitic structure. Although metals T and N do not attain this structure, yet they respond to quenching. Their Brinell hardness number increases from about 100 to about 200. These last two metals quench similarly to mild steel, which they are, while metal B quenches like a steel containing more carbon than its analysis indicates.

Under the microscope all three metals look as if they contained hardly any carbon. We there see only a negligible quantity of pearlite, and frequently we find no sign of it although it should occupy from a ninth to a sixth of the area. This relative paucity of pearlite has been observed by others, notably by S. W. Miller in America.

Thus one sees upon close inspection that weld metal presents several curious anomalies whose systematic study would surely be worth while.

Conclusions. Our observations confirm the opinion of welding experts that welds are not improved by annealing. Moreover, in the field of construction which we have in immediate view, annealing would usually be impracticable.

Our observation seems to show that, by itself, the typical structure cannot be held responsible for the poor behavior of welds under the Charpy test (see below), since its absence hardly changes the result.

To sum up, one will be especially struck by the tremendous differences in properties that exist between metals deposited from different wires,

despite the fact that these metals have chemical properties that are nearly alike.

V. Effect of Weld on Base Metal

It is sometimes supposed that the weld seriously changes and weakens the base metal on which it is deposited. This assumption is based on the following premises:

In tests on welded joints it is found that rupture frequently occurs fairly close to the weld. It would seem as if the effect of welding was to transfer the locus of rupture to a point on the base metal that is one or two times its thickness away.

Now, we have seen that both microscopic inspection and hardness tests show clearly that the structure of the base metal is modified only to a depth of less than a millimeter.

Here is an apparent contradiction. Whence can it arise? Experiments made shortly after we commenced our investigation supply a probable answer. On the 18th of February, 1925, portions of three bars, welded at the middle with wire T, were subjected to tension after having been turned to 0.79 in. in diameter. All three very clearly showed necking at points on each side of the weld, after which they broke, about half an inch away from the weld, under stresses of 53.5, 53.5, and 53.2 kips per sq. in.

From remaining portions of the same bars we made unwelded specimens 0.79 in. round, and pulled them with the results shown in Table A.

Table A

Comparative Tests on Plain Steel Bars

Property	Untreated	Annealed 10 min. at 900° C.
Tensile Strength (Kips per sq. in.).....	67.2	50.7
Percent Elongation in 7.9 in.....	12.0	32.0
Brinell Hardness Number	160	60

Note. A Kip is 1000 pounds.

The tensile strength of weld metal T is 56.9 kips (see above), which is intermediate between that of the untreated and the annealed plain bars. We are dealing therefore with a base metal very sensitive to heat, which in its untreated condition has a tensile strength definitely higher, and in its annealed condition quite a little lower, than that of the weld. This accords with observation.

In the process of welding what do we find? The piece is raised gradually to a bright red color over a length that varies with its thickness and with the volume of the weld. It then cools freely in air. This means that near the weld the piece undrgoes precisely the same treatment as would normalize mild steel.

If the base metal were in a state of normalization the weld would not change any of its mechanical properties. If it is partially annealed or cold worked, it will approach a state of normalization, but with a somewhat lower breaking strength. From the fact that rupture in welded

joints is often found to occur in the vicinity of the weld, we are brought to the conclusion that a state of normalization is not usual in commercial rolled steel.

The basis of this conclusion was confirmed by a simple experiment. We selected at random several commercial sections furnished for construction work at the University. From each we cut 6 specimens, of which 3 were pulled in their original unannealed condition, and 3 after being heated 10 minutes at 900 deg. C. and cooled in air. There were 2 angles, 1 channel, 1 I beam, 2 concrete reinforcement bars, and 2 forging flats. Of the 8 products thus tested, 4 gave similar results before and after annealing, and the other 4 gave the results shown in Table B.

Table B

Comparative Tests on Plain Structural Material

	Ult. T. S. (Kips per Sq. In.)		
Material	Untreated	Annealed (Aver. of 3 Tests)	Loss Percent
Angle, 4.1″ by 4.1″.....	50.6	46.4	8.5
Forging Flat, 3.34″ by 1.18″..	60.5	57.0	6.0
Concr. Reinf. Bar, 0.79″ diam..	57.7	54.9	5.0
Forging Flat, 1.57″ by 0.59″..	56.4	53.7	4.5

We may therefore say that the only effect of the weld on a base metal composed of mild steel is to cause it to undergo normalization near the weld. The treatment brings commercial rolled products to the condition in which they are supposed to be delivered and put in service.

VI. Mechanical Properties of the Weld

Complete joints are not well suited to the determination of all mechanical properties. The only ones we can ascertain thereby, with any degree of accuracy, are ultimate tensile and shearing strengths. For other properties we must employ specimens made wholly of weld metal.

The preparation of such specimens is tedious and costly, especially when long pieces are required. We prepared only the number strictly necessary. These specimens were made by depositing successive layers of metal in a deep groove channeled into a plate. The large deposits thus obtained were welded endwise to two grip-bars of steel having a strength of 85 kips per sq. in.

In reviewing current test reports on welds we have been struck by the following features:

1. Values for modulus of elasticity vary and sometimes depart widely from those usual in mild steel. For example, in the Lloyds' tests we find figures around 23,500 kips per square inch.
2. We find few or no tests that definitely indicate strength under shear.
3. In most of the ductility tests, specimens and deposits have been employed that differ too much from standard practice to give useful value to their conclusions.
4. Few fatigue tests have been made by reliable methods.

(a) *Modulus of Elasticity, E.* We know that E is almost constant in

different grades of steel. It would be remarkable if that of a weld, made out of mild steel of known composition, varied greatly from 30,000 kips.

By using a Martens mirror extensometer on samples measuring 0.39 by 7.90 in. between gage-marks, in a newly calibrated 5-ton Amsler testing machine, operated by hand, the results given in Table C were secured.

It is thus seen that out of several specimens selected haphazard, half were in unstable physical condition calculated to bring about just the kind of rupture that is criticized in welded joints.

Table C

Tests for Modulus of Elasticity

	Deposit from Wire	Kips per Sq. In.
1	B	30,000
2	B	29,400
3	T	29,600
4	T	28,900

These figures are quite normal. In other respects the stress-strain diagrams were regular, and showed but slight lack of homogeneity. In view of these very conclusive preliminary results we did not think it necessary to make more tests. We suspect the peculiar figures occasionally reported are due to experimental error.

(b) *Maximum Tensile Strength, Z.* When no other property than Z is desired the simplest way is to use "welded-butts," which are cylindrical specimens made as follows: Two bars of hot-rolled round steel roughly pointed are aligned on a plate and united by a volume of weld metal whose length is two or three times the diameter of the bars. The weld portion is then machined to a diameter slightly less than that of the bars, so as to localize the point of rupture.

These specimens, which are easy to test and quite inexpensive to prepare, were made and broken in large number. Anticipating that the unit strength of small specimens would be somewhat higher than that of larger ones, for each type of wire we prepared a series with diameters of 0.39, 0.79 and 1.18 in.

Table I gives a summary of the test results, and shows that:

1. The weld as a whole is uniform, but its degree of uniformity depends chiefly on the quality of wire used.
2. The Z of welds made with wires T and N is similar to that of the structural base metals we wish to unite. The Z of welds made with wire B is considerably higher.
3. Large welds are somewhat weaker per unit than smaller ones.
4. (Added by Translator.) No major defects are recorded for the largest welds made from any of the wires.

This series of tests was made on our horizontal 30-ton Amsler machine, which is well suited to repetitive work.

One notices a net falling-off in the Z of the 1.18 in. welded-butts as compared with the 0.39 and 0.79 in. specimens. This may be caused

by a prevalence of minor defects (inclusions or pockets) localized centrally. They may be attributable to the difficulty, increasing as the section increases, of making a weld that is perfect at the root.

TABLE I

Tension Tests on 105 Welded-Butts
Maximum Strength in Kips per Sq. Inch

Metal B			Metal T			Metal N		
Diameter (Inches)			Diameter (Inches)			Diameter (Inches)		
0.39	0.79	1.18	0.39	0.79	1.18	0.39	0.79	1.18
69.8	78.4	71.1	54.1	59.9	58.5	43.4A	42.7A	47.8
69.8	76.9	69.8	42.8A	59.9	60.6	40.6A	37.8A	46.4
74.0	67.6	71.1	39.9A	62.6	60.6	44.1A	36.4A	46.4
72.5	75.5	73.5	44.2A	62.6	64.7	42.7A	46.5	47.8
74.0	66.9	63.8	57.0	57.7	48.3	49.8	49.8	41.3
68.3	71.1	59.1	59.2	60.5	51.2	54.0	52.0	41.2
....	73.4	61.2	43.5A	57.0	49.8	44.1A	52.0	40.6
....	74.0	68.2	58.4	57.0	....	49.1	49.8	....
....	71.1	59.8	57.6	50.5	....	41.3A	49.8	....
....	75.5	65.5	64.7	60.5	....	54.0	49.8	....
....	62.6	64.0	64.7	53.4	....	59.8	56.3	....
....	62.6	....	59.1	62.6	....	57.0	54.0	....
....	66.9	....	55.5	58.4	....	....	54.0	....
....	76.9	....	....	57.0	....	....	....	....
....	76.9	....	....	56.1	....	....	....	....
....	68.3	....	....	57.0	....	....	....	....
....	75.5	....	....	57.0	....	....	....	....
....	....	....	....	57.0	....	....	....	....
....	....	....	....	56.6	....	....	....	....
Gross Averages								
71.3	71.7	66.0	54.0	59.0	56.2	48.4	48.4	44.4
....	....	....	59.0*	....	....	54.0*	51.3*	....

**Net Averages*, disregarding 13 specimens with evident defects (A).

(c) *Appearance of Fracture.* Although this large number of welded-butts developed almost uniform strength, yet their fractures vary greatly in appearance. For example, very high strength will be accompanied by a granular fracture, or it may even show dark spots and suspicious-looking variations in color. On the other hand, fine appearing fractures may correspond with results scarcely up to the average.

An examination of these fractures, confirmed by that of all other specimens tested, led us to a seemingly paradoxical conclusion, which however is borne out by numerous examples, namely: In the testing of arc welds there is no relation between the appearance of internal fractures and the strength of specimens.

If, instead of observing the fracture with the naked eye or a magnifying glass, a metallographic section be cut near the fracture, we reach a similar conclusion. The relative distribution of different kinds of structure found in the section appears to have no bearing on the results of mechanical test.

TABLE II

Slow Tension Tests on Welded-Butts

Metal	Kips per Sq. Inch		Per Cent Elongation	Foot-Pounds Work of Rupture
	Elastic Limit	Max. Tens. Strength		
B 1	54.5	72.5	20.0	520
2	50.0	72.1	22.7	579
3	55.0	71.3	18.9	517
4	50.0	71.1	24.0	636
5	49.8	69.8	10.0A	217
6	51.2	62.6	7.6A	181
Average.....	51.3	69.8	....	(Spec. 1 to 4) 565
T 1	46.5	59.8	25.0	565
2	44.1	58.0	18.7	390
3	41.7	57.0	14.2	296
4	39.4	56.1	18.5	376
5	43.9	56.0	....B	....
6	42.0	52.7	7.6A	136
Average.....	42.4	56.7	....	(Spec. 1 to 4) 405
N 1	43.4	55.2	19.3	396
2	43.0	56.0	20.0	405
3	41.5	54.3	....B	....
4	28.4	59.7	....B	....
5	31.3	51.2	4.1C	....
6	34.1	42.7	3.0C	....
7	39.8	55.5	16.0D	....
8	39.8	54.0	12.0D	....
9	38.4	55.5	12.0D	....
Average.....	38.4	53.8	....	....

A. No serious defect visible.
B. Broke beyond gage-marks.
C. Serious visible defects.
D. Broke between shoulders, but beyond range of extensometer.

(d) *Elastic Limit, L; Elongation, A; and Work of Rupture, W.* These different properties were determined by tension-tests on a series of specimens deposited from each of the wires B, T, and N. The specimens were 0.39 in. in diameter and 3.90 in. between shoulders. They were inserted in our 5-ton Amsler machine and pulled at slow speed, a diagram being taken in each case. Table II gives the results.

The first feature that stands out in this table is the importance of wire-quality when applied to a job as difficult as the depositing of weld

metal in a long specimen free from defects. All specimens were prepared by the same welder. Those from wire B were the first of the kind he had made. Those from wire N were made last, when he had acquired facility in such work. It is interesting to note the extent to which irregularities varied with the kind of wire used.

Elastic Limit, L. We considered L to be the usual value as indicated by the landing in the stress-strain diagram. It is to be noted that, in the case of each wire, L is constant and quite high. Whereas we are wont to place the L of mild steel at approximately one-half of Z, we find that for T and N metal it is three-fourths, and for B metal four-fifths.

These high values put weld metal in the category of special steels rather than that of ordinary carbon steel. (Wire B of course does carry a little nickel). When considering joints that are subjected to elusive secondary stresses, these values serve to increase the factor of safety.

Elongation, A; Work of Rupture, W. If the results are tabulated in sequence of strength, it will be seen that A and Z increase together. This is the converse of what usually occurs in steel.

The stress-strain diagrams for the same kind of wire could almost be superimposed. They differed in the variable length of arm denoting high elongation. Necking, with final break, occurred at a variable point on this almost horizontal arm where a large increase in A was accompanied by a small increase in Z.

If one examines a long specimen of weld metal broken in tension, there is seen on the outside a series of small irregularities and minute cracks that denote the presence of minor faults in homogeneity. We believe it is to these minor faults, difficult to avoid and the more frequent as wire-quality deteriorates, that we must attribute differences in elongation.

Since A is somewhat irregular, it follows that when this feature affects practical calculations, we should assume only a low percentage. The same caution applies to W. As regards zone of permanent set, metal N is a rather dangerous material. In the preparation of specimens to be treated beyond their elastic limit, the wire chosen will greatly affect results.

(e) *Shearing Strength, Z* 2; *Elastic Limit Under Shear, L* 2; *Modulus of Elasticity Under Shear, E* 2. We investigated the shearing strength of specimens 0.39 in. square placed diagonally as to section in a suitable apparatus whose shear-blocks exactly matched. We are aware that results thus obtained err on the side of excess, but we shrank from the difficulty of welding specimens of a kind that would give more precise values. No specimens were made from wire N. The results are summarized in Table III.

The figures are remarkably regular. If we compare them with the slow-speed tensile results of Table II, we see that for weld metal the ratio of Z 2 to Z is about 0.7, which is also the ratio for mild steel.

Table III

Ultimate Strength Under Shear

Test No.	Total Shearing Stress in Kips	
	Metal B	Metal T
1	14.5	12.7
2	14.6	12.5
3	14.6	12.6
4	14.6	12.5
5	12.4	12.9
6	....	12.7
7	....	12.6
8	....	12.3
Averages	14.5	12.6
Aver. per Sq. In.	48.0	40.8

In view of the prevalence of shearing stress in welded structural joints, we endeavored by torsion test to determine the corresponding L 2 and E 2 values. For this purpose we prepared specimens similar to those used in the slow tension tests (Table II), but twice as large. They were machined to 0.79 in. in diameter, and their torsion was observed between gage-marks 7.90 in. apart. The tests were carried out on our 660-lb. Amsler torsion machine calibrated at 220 lb.

Two B specimens showed an L 2 of 26.6 kips per sq. in., and an E 2 of 20,800 kips. Two T specimens gave an L 2 of 22.5 and an E 2 of 21,900 kips. These values were obtained by observing as closely as possible the initial dip on a torsion diagram. Another B and another T specimen, giving L 2 of 26.6 and 19.8 kips respectively, were observed by Upton's graphical method. All results are probably correct within 3 per cent.

If we compare these values with those of Table II we see that the ratio of L 2 to L is about 0.5. This seems low, but not abnormal. As a matter of fact, in several experiments with high grade structural steel, we have found results which gave ratios of about 0.6. Besides, in the case of weld metal, not only is the denominator intrinsically large, but it is also aggravated by having been determined from the landing in stress-strain diagrams.

As regards moduli of elasticity, we find the ratio of E 2 to E to be about 0.7 for metal B, and 0.75 for metal T, which is in line with ratios for mild steel.

(f) *Impact.* In these tests we used the small Charpy specimen of the French Standards Association, wherein the hole is increased to a diameter of 2 millimeters for easier machining. These small specimens are readily made and their cost is trivial. They were tested on our small 100-Foot-Lb. Amsler impact machine, with apparatus and ram as per French standard practice, which is the same as Charpy's. The results are summarized in Table IV.

Specimen No. 11 was defective. The two T values marked (A) are inexplicable. They were part of a series whose results are otherwise

normal. The machine was calibrated at both beginning and end of the series. Neither the fracture nor a metallographic examination exhibited abnormal features.

Table IV

Impact Tests on Small Charpy Specimens, 0.39 In. Sq. by 2.16 In. Lg.

Test Number	Work of Rupture (Foot lb. per Sq. In.) Metal B	Metal T	Metal N
1	242	28	37
2	242	28	37
3	242	28	37
4	242	37	37
5	261	37	37
6	261	42	30
7	298	140A	40
8	303	200A	35
9	280	..	42
10	289	..	42
11	163A	..	47
12	224	..	..
13	252	..	..
14	252	..	..
Aver. disregarding A	242	33	41

Table V

Impact Tests on Large Charpy Specimens, 1.18 In. Sq. by 6.30 In. Lg.

Metal	Foot-Pounds per Sq.In.					Average
B	378	345	540	..	..	420
T	59	65	58	57	..	58
N	20	57	55	30	13	35

The first impression made by the figures is of course the great inequality resulting from the respective wires used. If the B metal showing is accepted, then that of the T and N metals is frankly bad. The latter would make it appear that weld metal may be brittle, at least when deposited from wire that is not of unusually good quality. We shall see that such brittleness occurs only under special conditions.

Having learned that certain favorable published results of impact tests were being followed commercially in rather important work, we took occasion to make a series of Charpy specimens three times as large as those of Table IV, and broke them on our big universal Amsler impact machine, calibrated just before the tests for energies under 1450 Foot-Lbs. The results are given in Table V.

The showing of metal N was too discordant to be given further consideration. Comparing the other figures with those in Table IV, they indicate that large specimens show up much better than small ones. But they lead to a common conclusion as regards classification of wires.

(g) *Ductility.* Is it necessary to conclude, from the low results under impact test, that as a general proposition a weld will behave unsatisfactorily when confronted with such dynamic forces and shock as may occur in actual structures? There is no warrant for such a conclusion, for a welded joint is never subjected in practice to a condition comparable with the Charpy test.

In order to warrant us in passing an opinion on the ductility of welded joints, as they actually occur in service, we shall have to subject them to tests very different from those of Charpy.

A simple test, in which all data can be exactly determined, is the tensile impact test. We applied this on our universal Amsler impact machine, specially arranged for the purpose. We used specimens 0.39 in. in diameter and 3.90 in. between shoulders, similar to those previously studied under slow tension (Table II). The results are summarized in Table VI.

The N specimens broke under negligible energy, although they showed few major defects. All exhibited an exceedingly fine granular fracture

Table VI

Tensile Impact Tests

Metal	Calculated Work (Foot-Lbs.)	Elongation Per cent	Remarks
B1	608	19.0	
2	608	20.5	
3	710	....	Bent on Rebound
4	760	22.0	
5	650	19.5	
Average	658		
T1	491	17.0	
2	145	7.0	Visible Defect in Fracture
3	390	13.0	
4	195	6.0	Visible Defect in Fracture
5	383	11.0	
6	340	8.5	Small Defect in Fracture
7	556	16.5	
Average	(Spec, 1, 3, 5, 7) 455		
N1	405		Bent on Rebound
2	Negligible		Bad Defect Visible
3	Negligible		No Bad Defect Visible
4	Negligible		Bad Defect Visible
5	438	14.5	
6	Negligible		No Bad Defect Visible
7	249		Visible Defect
8	Negligible		No Bad Defect Visible
9	500		Bent on Rebound

resembling a very fine-grained cast steel. Metallurgical examination quite near the fracture showed a typical structure with no abnormal features.

Preliminary analysis of the three sets of results manifests the great difference between the qualities of our 3 wires. The number of anomalous N ruptures shows that little confidence can be placed in this wire as compared with B and T. The N welds resulted in rupture at insignificant load, despite the fact that few specimens contained defects visible to the naked eye, and that their micrographic structure near the fracture was the regular typical one.

Table VII

Slow Bend Tests on Small Charpy Specimens, 0.39 In. Sq. by 3.90 In. Span

	Charted Work of Rupture (Foot-Lb. per Sq. In.)		
Test Number	Metal B	Metal T	Metal N
1	85	77	37
2	104	93	30
3	87	51	40
4	113	75	35
5	112	228 A	42
6	108	249 A	47
Aver. disregarding A	101	74	38

The 2 results marked (A) cannot be explained.

In order to compare with Table IV, the results of Table VII must be doubled.

Twice Table VII Aver.	202	148	76
Table IV Aver.	242	33	41
Ratio	0.83	4.20	1.87

The N weld metal must be considered unreliable when subjected to much dynamic stress.

A comparison of Tables II and VI shows that, with similar B specimens, the work of rupture under sudden tension is definitely higher than that under slow stress, and that they develop no brittleness when subjected to tensile impact. In the case of T metal, the work under sudden is very little less than under slow pull, and its ductility under lengthwise impact is not bad. As regards the N metal, both sets of tests indicate irregular material, and a majority of distinctly brittle samples.

If we compare these results with the Charpy tests we see that the wires rank similarly. The B metal is manifestly the best. The N metal is bad. The T metal comes between, but it approaches B despite the fact that Charpy would rank it nearer to N.

In the unfavorable Charpy results we are led to ask what role is played by impact and what by the notch? In the solution of this problem it would seem desirable to vary only one of the factors while the other remains constant. For example, let us compare the results already

obtained with those corresponding with a greatly reduced impact, or as a limit with practically none.

This can be easily accomplished. On our 5-ton machine we arranged an anvil and ram identical with those of the small Charpy impact machine. We inserted several specimens, bent them till they broke, and charted the results on a flexure-diagram. The area of this diagram represented the work of rupture to a suitable scale. In this way we obtained the results given in Table VII.

If we compare these results with the Charpy tests summarized in Table IV, we see that the B metal resists much more in sudden bending than in slow bending (there being 20 per cent more work absorbed) just as it resisted sudden better than slow tension. The conclusion to be drawn is that metal deposited by wire B is entirely devoid of brittleness.

We see that T is classed by comparison with B metal almost as it is classed under slow and sudden tension (the work absorbed being about one-third less). But under the Charpy test its results are the lowest of all. Under sudden bending it absorbs only 22 per cent of the work it absorbs under slow bending.

As regards the N metal, we see that the work of rupture under slow bending, while low, is nearly twice what it absorbs under sudden bending. The latter is only 54 per cent of the former. But its unreliable character is evidenced throughout all the tests.

Such are the differences that seem to govern metals whose composition in general differs very little.

While we were engaged on these weld tests, the Bureau of Standards at Washington in 1925 carried out many comparative tests on the resistance of various metals under sudden and slow bending. From its Bulletin No. 289 it appears that for various low carbon steels the ratios of work of rupture, under sudden and slow bending, varied from 1.40 to 0.56. It would therefore seem that weld metal does not behave very differently from mild rolled steel in this respect.

The results of testing machined weld bars under slow bending, when compared with those produced under slow tension, indicate a characteristic that may be called "Tearing Tendency." It is explained in further detail at the end of this paper.

(h) *Fatigue.* Tests for fatigue were made on our Alpha machine by subjecting to rotative bending a weld metal specimen machined to a diameter of 0.39 in. at the middle. The specimen was mounted on 4 small ball-bearing wheels of S. K. F. make. The two end wheels serve as chucks, and the two intermediate ones transmit the bending load to the specimen. These wheels are arranged symmetrically as regards the prepared portion of the specimen, and the latter is subjected to a constantly alternating bending moment.

The purpose of such tests, which last a very long time, is to determine "endurance limit," namely, the amount of alternating tension the metal can withstand for an infinite time without breaking. We assumed endurance limit to be the asymptote of Wöhlers curve, using extreme fiber

stresses as ordinates, and the number of revolutions that are required to produce rupture under these stresses as abscissas.

It is well known that in delicate tests like these a slight error in workmanship on the specimen, or a hardly visible defect, is sufficient to greatly reduce the number of cycles needed to cause failure.

We did not apply these tedious tests to N metal which, on account of its metallographic composition, might be expected to give poor and irregular results. In the case of the B and T metal we have seen that, under tension test, they exhibited minor indications of non-homogeneity which were brought out during the period of excessive deformation preceding rupture. What would be the effect of these indications under long repeated stress well below the elastic limit? It would be rash to prophesy.

As a matter of fact, our fatigue tests gave disconcertingly irregular results. Even with B metal we could not locate Wöhler's curve. It appears as if, when pressure is gradually decreased, the specimens tend more and more to range themselves in two groups. In one, which is the most numerous, rupture ensues very quickly. In the other, which is less numerous, rupture ensues, if at all, only after a number of cycles gradually increasing in number.

Take the B metal for example. Out of a dozen specimens tested at half their elastic limit as per Table II, three stood up without breaking for 5,600,000; 10,000,000; and 10,000,000 cycles. In the first case the test was interrupted by a short circuit. Of the other nine, one lasted 816,500 cycles, while the remainder ranged between 210,800 and 37,500 cycles.

Inspection of the fracture in these last specimens showed it was produced by the enlargement of a small defect near the surface—a slag-inclusion, a blow-hole, or merely a point of weakness as indicated by some variation in grain or color.

The preceding figures show that for metal B the endurance limit as defined above should be very close to half its elastic limit, namely, 25.6 kips per sq. in. The less numerous class of tests made on T metal indicate that its endurance limit should also be about half its elastic limit, namely, 21.4 kips. But this presupposes faultless, homogeneous metal in the region affected. Experience shows that we cannot depend on such perfection.

It may be noted that Lloyds' Rules require the weld to resist a stress of 12.8 kips per sq. in. for 5 million cycles. In the case of metal B this would be only one-fourth of its elastic limit. We made no tests at stresses as low as this. It might be advisable to do so in order to settle the following point: Is there a value (no matter how low) that can be considered an endurance limit for welds characterized by ordinary minor defects? Such tests would necessarily be very tedious.

Conclusions

From the preceding test results we can draw the following tentative conclusions as regards the arc welding of mild structural steel:

1. The feature that outweighs everything else is the great importance of a proper selection of welding wire.
2. The metal deposited by good wire behaves, under static test, like mild steel as regards ultimate strength, elastic limit and modulus of elasticity, in both tension and shear. It is normal and quite regular as regards these properties.
3. It follows that the dimensions of welded joints can be calculated and determined with safety.
4. Elongation is not very regular. In cases where work of rupture must be considered, it will be wise to assume only a low elongation, even with good grades of wire.
5. The Charpy test by itself is quite incapable of determining the ductility of welds. The wires investigated, when subjected to dynamic conditions, did not behave alike. Tests that represent service conditions, as nearly as possible, are urgently needed.
6. Our fatigue tests were not conclusive and should be extended. As far as they go they indicate that caution should be exercised in the use of welded joints that are to be subjected to alternating repeated stress of considerable amount.
7. In general the tests seem to indicate a peculiar property in weld metal, a "tearing tendency," which must be taken into consideration in the design of joints.
8. The process of welding does not adversely affect the base metal—certainly not if it is mild steel. It gives a highly localized normalizing treatment, with exactly the same results as accompany the well known process of heat treatment.
9. There is no advantage in annealing welds.

Brussels, May, 1926.

Special Note on Tearing Tendency.

Early in 1925 we made several destructive tests on sample joints. During a number of the experiments we were struck with the low additional pull needed to produce final rupture when once it was approached, although maximum tensile strength was always high.

A little later we were able to take account of the precautions needed to avoid abnormal results in bend tests, which are the kind most used for commercial welds. It was found necessary to carefully avoid anything that might invite tearing or ripping in the strained portion of a specimen. Our slow bend tests, especially with B metal, showed the effect of the notch, although it had a good bottom radius. Inspection of the long specimens broken under slow tension, and of those broken under torsion, in tests from which we had eliminated marked irregularities, disclosed many cases of rupture by progressive ripping of the metal starting from an insignificant beginning.

The tests generally gave us the impression that, in metal deposited by welding, even a very incipient tearing progresses more readily than in the case of mild rolled steel of similar composition. This tearing tendency, combined with such minor defects in homogeneity as must be considered normal and unavoidable in a cast metal that has undergone no mechanical work, suggests a possible explanation for the peculiar behavior of arc welds in some of the tests.

Erection of Buildings by Welding*

J. F. LINCOLN†

WHILE arc welding will undoubtedly replace the rivet as a means of fabrication and erection of structural steel, yet the chance for great economic gain by the application of the process is less in this field than in many others which are now almost neglected.

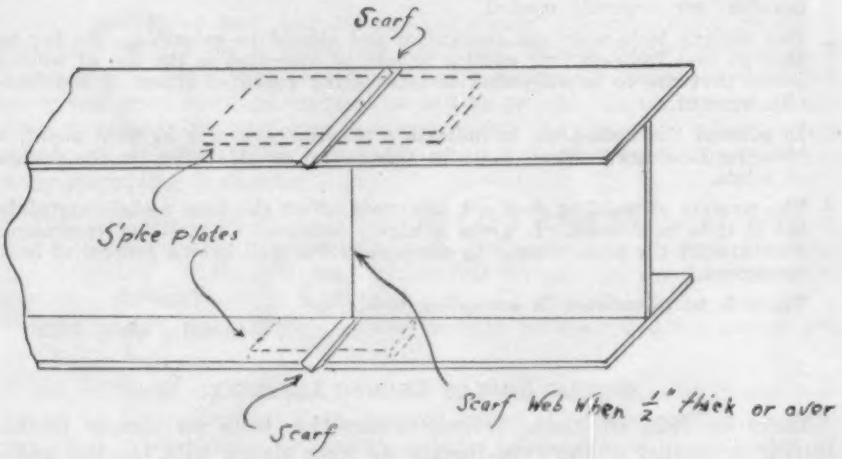


FIG. 1. BEAM SPLICE

This sketch shows scarfing of ends of beams to get a satisfactory field weld. As indicated, it is not necessary to scarf the webs unless they are more than half inch thick. If necessary, splice plates can be put on top of top and bottom flanges, making all welds on them horizontal.
(Double scarfing on flanges leaves very thin edge which burns through easily and necessitates overhead welding).

The fundamental reason for this lesser possibility lies in the fact that the total cost of labor in the erection and fabrication of any building is still a small part of its total cost and any saving must be of this small part. Further, there has not so far been worked out a design which will allow the use of automatic welding in this application although the present day method of fabrication of structural steel in the shape for riveting is using automatic or semi-automatic equipment to a considerable extent.

Arc welding, however, has been applied to hundreds of buildings which have been completely erected by the use of this new tool. Thousands of other buildings have used this new tool to some extent.

The first structure in this country which used arc welding in an important part of the erection of a building, was in the plant of The Lincoln

*Paper to be presented at Fall Meeting, A. W. S., October, 1928.
†Vice-President, Lincoln Electric Co.

Electric Company, in 1916, where all of the columns were erected for a four-story plant by welding.

The first bridge to use this process was the vehicular bridge in Toronto which carries all of the traffic in one of the main arteries in the Northeast direction. This was entirely erected by welding in 1923 by the same company.

There has been erected however, within the last ninety days, at the corner of East 105th Street and Carnegie Avenue (which is one of the most important corners in the City of Cleveland), by the Austin Company, who are themselves builders, a four-story business block. This was entirely welded, being designed by their engineers and the engineers

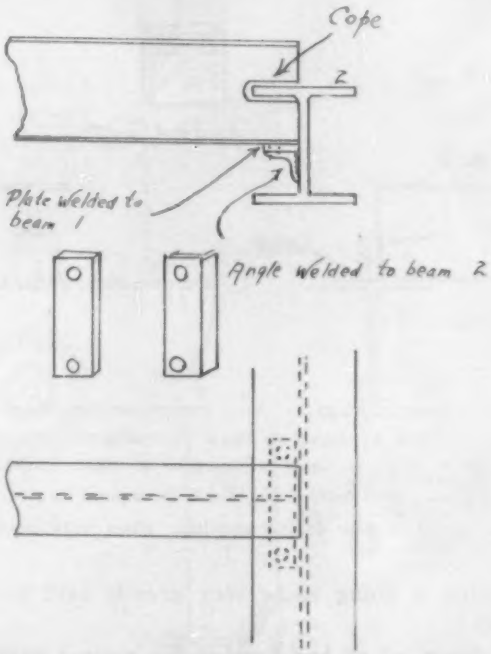


FIG. 2. BEAM TO BEAM CONNECTION

This sketch shows a beam to beam connection at right angles and at different elevations. In this case a plate having two holes punched in it would be welded to beam No. 1 at the mill while an angle with two holes punched in it would be welded to beam No. 2 at the mill.

Connection to be bolted in field during erection. Field welding done along webs and flange, making horizontal and vertical weld.

of The Lincoln Electric Company, the welding work being done by The Lincoln Electric Company. Many buildings which have so far been built by this process have been done at a loss compared to the best practice by the riveting method.

There have undoubtedly been a number of cases where arc welding has been used to advantage in which the matter of cost does not enter at all —such as the elimination of noise and other special cases.

The reason for this high cost and slow acceptance of this process is as follows:

First: There is not a trained personnel for doing the work. The erection of steel work is done almost entirely by the Steel Workers' Union, who are skilled in the erection of riveted steel, who have had no experience whatsoever in welding and because of the fact that a chance of their getting on a welded job is rather remote, they are showing no particular desire to learn this new process. As long as the Steel Workers' Union controls the situation which they do in every city in the country,

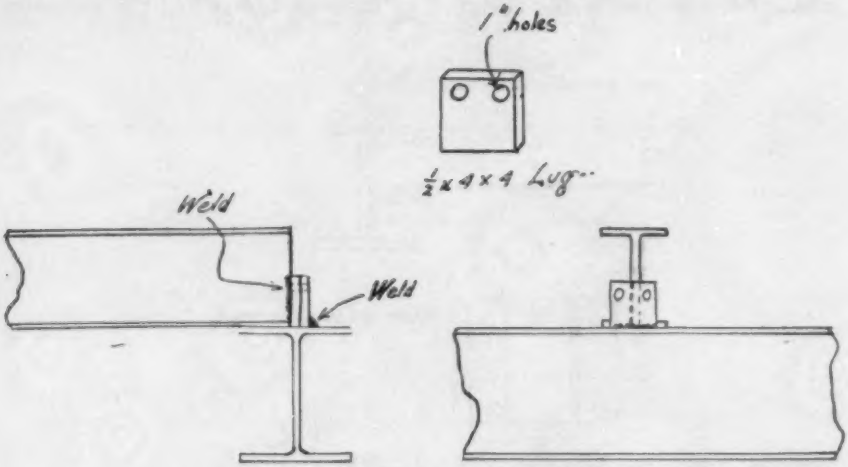


FIG. 3. BEAM TO BEAM CONNECTIONS

This sketch shows a beam to beam connection at right angles, with one beam resting on top of the other.
In this case, a flat plate field bolting lug would be welded to each beam at the mill so that the holes in each will line up.
Connection to be bolted in field during erection. Field weld would be made along bottom flange of top beam.

economical erection is going to be very greatly held back unless their attitude changes.

Second: The design of all buildings so far erected have, more or less, followed the tradition established by the riveted method and we see the rather hopeless situation of designers insisting upon the entire structure being designed exactly the same as it would be for rivets, the only change being the elimination of the rivet and the replacement of it by weld.

It is so self-evident that this new tool requires new design, that it is only necessary to state the fact to draw the conclusion. It is self-evident that by proper design a number of very considerable savings can be made with the application of this new process, chief of these are the following:

All beams can be made continuous, thus materially reducing the amount of steel which is necessary to put in them for the same strength.

All columns can be stepped—in other words, the amount of steel necessary for a column on the lower floor is very much greater than that necessary for the same column on the top floor. With welding this reduction in section can be obtained easily. Parts which are used to make riveting possible can also all be eliminated. In many built up sections it is possible to reinforce the beam or column in such a way as to cut down materially the weight because of variable strength requirements of the section in various parts of it. Thus, it is self-evident that

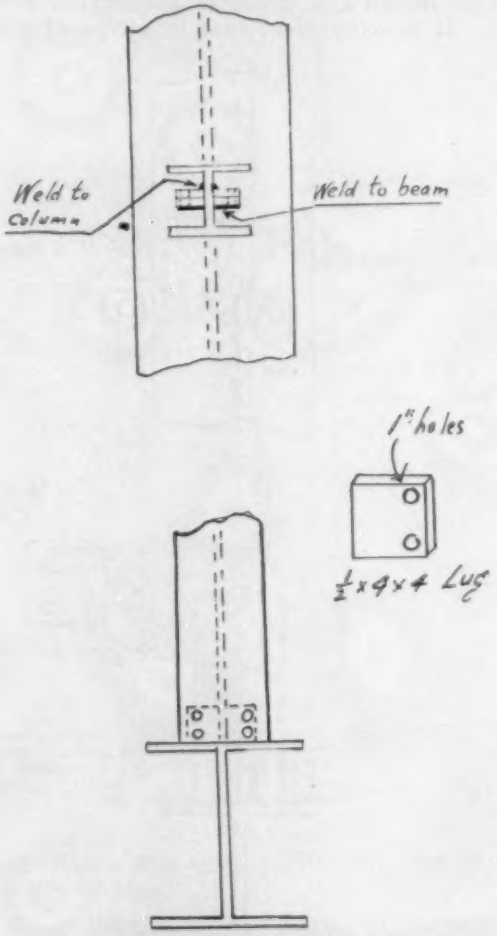


FIG. 4. COLUMN TO BEAM CONNECTION

This sketch shows a column to beam connection, the column being narrower than the beam. In this case the end of the column would be milled. Two flat plate field bolting lugs would be welded to the column webs and two to the beam at the mill so that holes will line up.

Connection would be bolted in field during erection. Field welding would be horizontal across column flanges.

In cases where beam rests on top of column field welding would be overhead across column flanges.

(Overhead weld inside of flange not very satisfactory due to arc blow encountered).

a beam needs its maximum strength in the center only, its strength requirement decreasing to zero, or practically zero, at the supports. This type of beam can be easily built by the application of welding—it cannot be built economically in most cases by riveting.

These are merely indications of some of the advantages which can be obtained by the application of arc welding if it is applied without the traditional ideas which have been built up in the minds of engineers and architects with riveted construction.

With the proper design also, overhead and vertical welding can be cut to a minimum. It is self-evident that this type of weld is somewhat

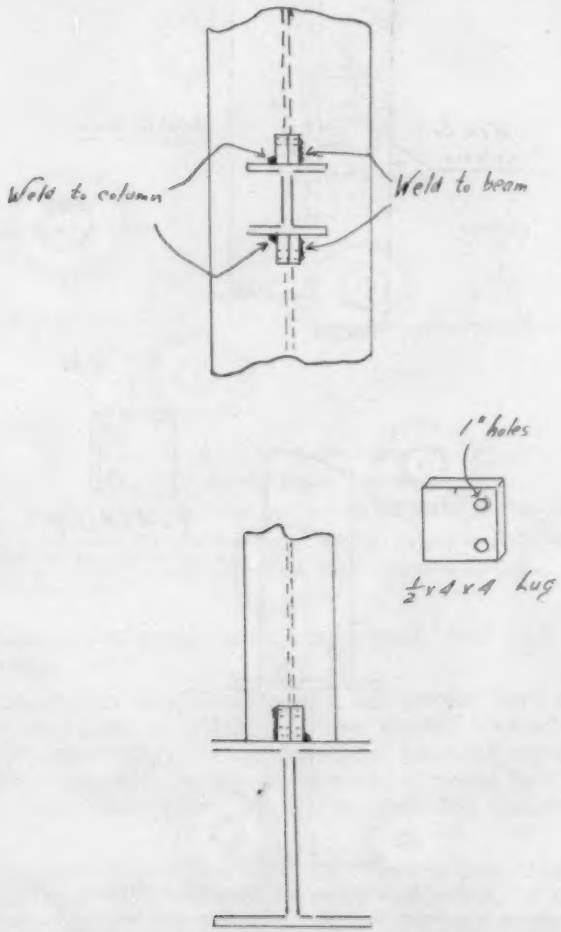


FIG. 5. COLUMN TO BEAM CONNECTION

This sketch shows a column to beam connection the same as Fig. 4, except that bolting lugs are welded to flange of column instead of web, at the mill.
Field bolting would be somewhat easier.
Lugs would also act as gusset plates to give stiffness to connection.
Field welding would be along lugs and column flanges.

unsatisfactory so far as strength is concerned. It is extremely slow to make compared to the flat weld and requires generally a good deal of trouble in getting the operator in the proper position for doing it.

Proper design will eliminate this type of welding almost entirely. The vertical weld while very much easier to weld than the overhead weld, is

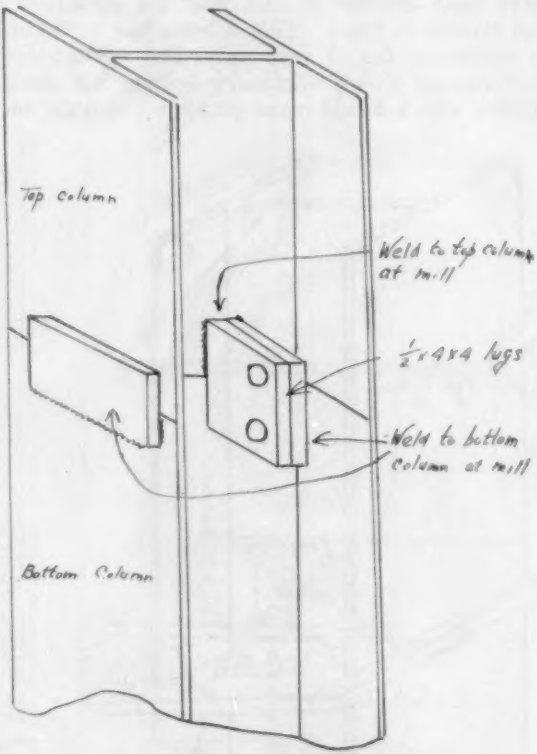


FIG. 6. COLUMN SPLICE

This sketch shows a column splice between same size columns. Here field bolting lugs would be welded to each column at mill so holes will line up. Splice plates would also be welded to flanges of bottom column at mill.
Field connection to be bolts.
Field welding around bolting lugs and splice plates.

still not as good as the flat weld. This also, can in most cases be eliminated by proper design.

Third: The third difficulty is the matter of technique. Almost all buildings so far have been welded by the use of ⅛ in., 5/32 in. and 3/16 in. electrode, using currents of 100, 150 to 180 amperes. It is safe to say that for vertical and flat welding in the usual structure there is no use for any one of these three electrodes. All welding should be done with the ¼ in., 5/16 in. or even the ⅜ in. electrode, using currents up to 400 ampere or even higher. The only place where electrode as small as 3/16

in. should ever be used is for overhead welding, and as stated above, overhead welding should be eliminated.

The method of erection used in riveted structures is as follows: the beams and columns are swung into place and after lining up the two proper holes the tail of the erector's wrench is inserted in this hole, after which it is bolted in place. After one or two stories, or perhaps even more, have been erected in this way the structure can be made plumb and then riveted in place. This scheme has been very successfully used and the technique for it very carefully worked out in riveting. Welding cannot replace this preliminary bolting up since a weld is a positive connection which would make plumbing impossible. There have

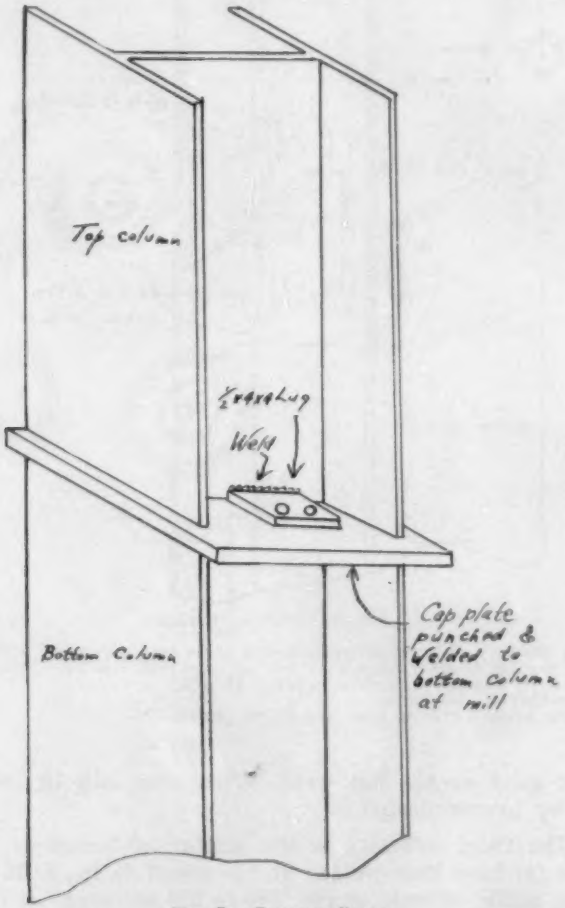


FIG. 7. COLUMN SPLICE

This sketch shows a column splice between same size or different size columns. In this case field bolting lugs would be welded to top column at mill. A cap plate having holes to line up with bolting lugs would be welded to bottom column at mill. Field connection would be bolted.
Field welding would be horizontal between flanges of top column and cap plate.

been a number of attempts made to accomplish with welding the same erection results as obtained with riveting—one of these is the punching of sufficient holes so that the erection of the building can take place in similar manner as in the riveted structure. This is not economical since it is but little more costly to completely punch and erect by rivets. Therefore, in order to do this job economically it is necessary to eliminate

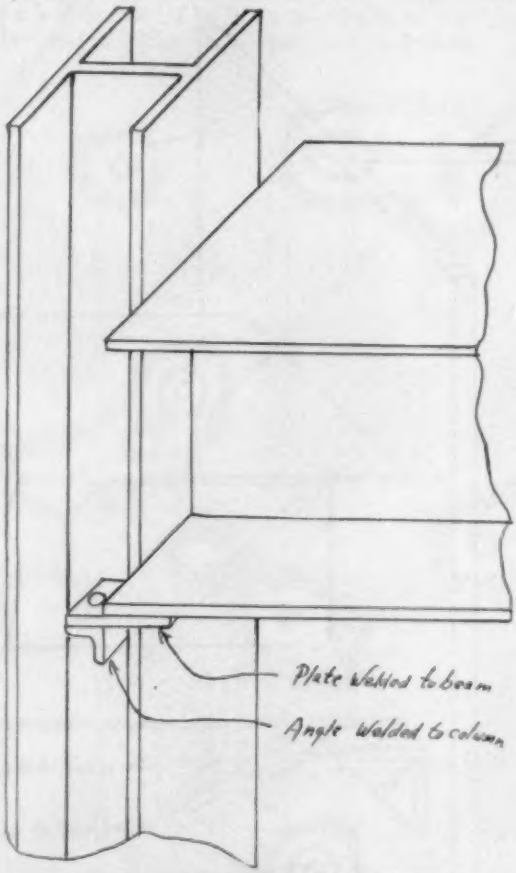


FIG. 8. BEAM TO COLUMN CONNECTION

This sketch shows a beam to column connection where the beam is wider than column. Here flat plates with holes for field bolts would be welded to the bottom flange of beam and angles with corresponding holes would be welded to inside of column flanges at mill.

Field connection would be bolted.

Field welding would be horizontal across beam flanges and vertical along web if required.

punching entirely in the parts to be erected and still have some scheme whereby the bolted construction can be used up to the point of welding the plumbed building.

This paper has to do considerably with a suggested scheme for accomplishing this purpose.

Fourth: The fourth difficulty is the lack of a proper building code. Because of that in almost all buildings which have been erected, the design has been a compromise. Frequently after the building has been designed by the engineer in a way which is entirely satisfactory, a building inspector will insist that certain parts don't look to him to be strong and insist that additional welding be done, frequently interfering very materially with the method of erection and with the design.

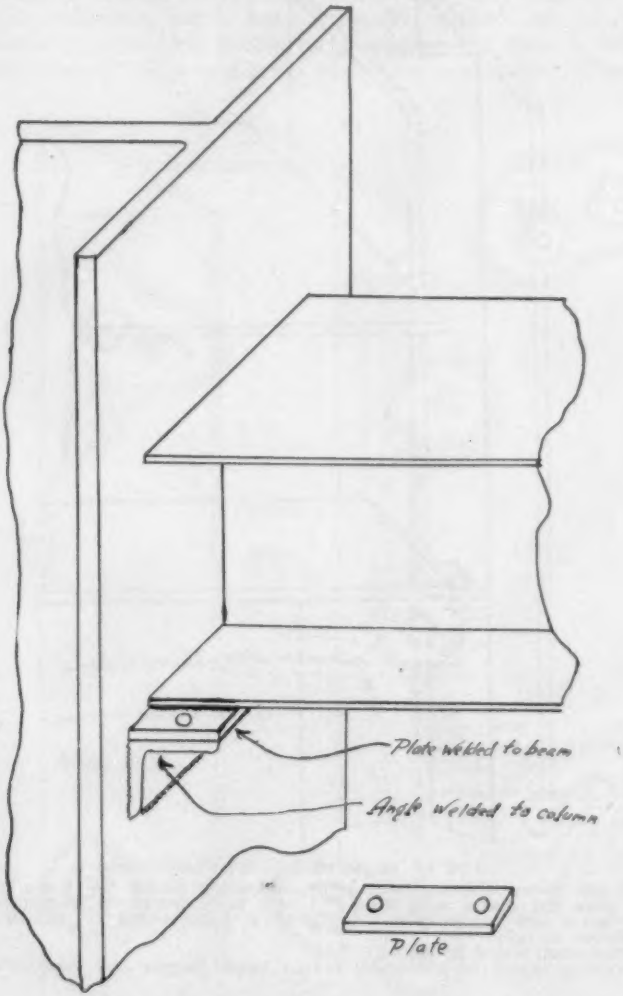


FIG. 9. BEAM TO COLUMN CONNECTION

This sketch shows a beam to column connection where the beam is narrower than the column. Here a flat plat would be welded to the bottom flange of beam and an angle would be welded to column, each provided with holes for field bolts. Above welding to be done at mill.

Field connection would be bolted.

Field welding would be horizontal across beam flanges and vertical along web if required.

There is also no accepted data as to the strength of fillet welds, which the building inspectors will acknowledge. For that reason the amount of weld which is put on is frequently from two to two hundred times the amount which is acutlally required.

It therefore seems to me that the following things should be done if we are to take advantage of this new tool in the manufacture of buildings:

First: All designing should be done to eliminate overhead welding and only as much vertical welding as is absolutely essential.

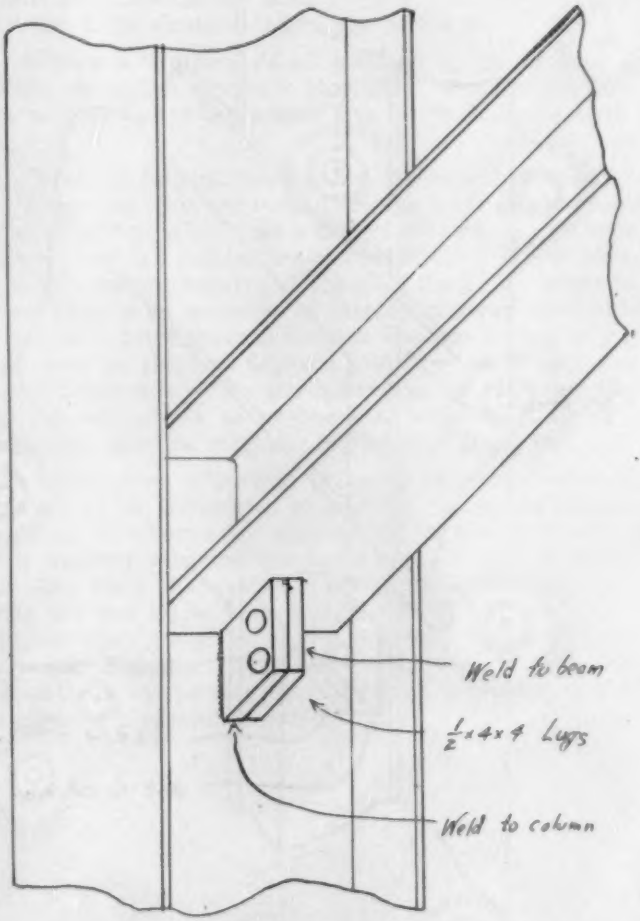


FIG. 10. BEAM TO COLUMN CONNECTION

This sketch shows a beam to column connection, the beam framing into the web of column, with the beam narrower than column. Here field bolting lugs would be welded to beam and column at mill.

Field connection would be bolted.

Field welding would be horizontal across beam flanges and vertical along web if required.

Second: The amount of weld and its placing should be a matter of fact based on proved results rather than a matter of opinion of people who are not in position to know.

Third: Continuous beams and stepped columns should be used. Where stiffening braces are used these should be put in in such a way as to do the most good in the light of welding.

Fourth: Change the present method of erection as little as possible. Make it possible for the present types of labor who are successfuly erect-

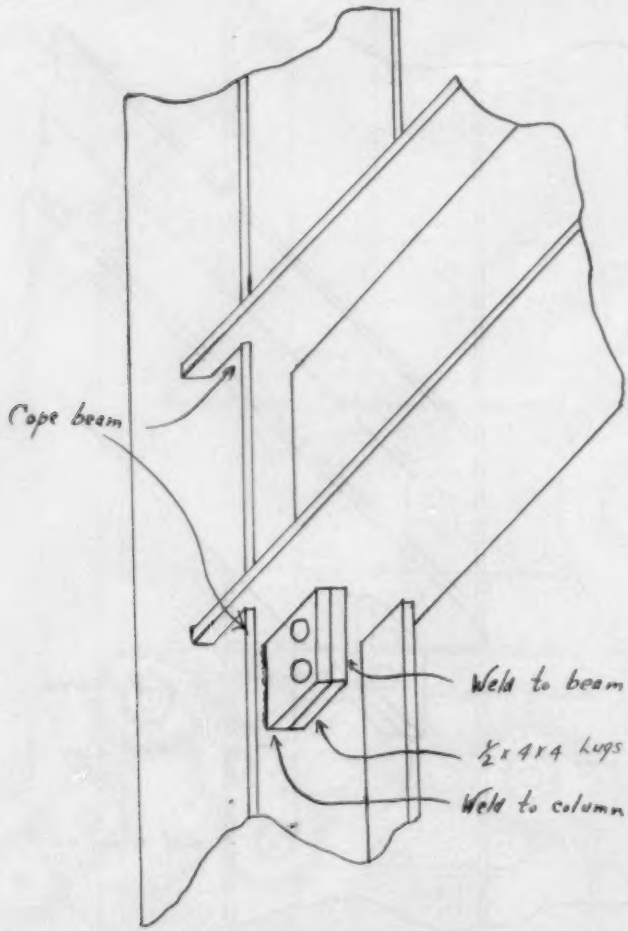


FIG. 11. BEAM TO COLUMN CONNECTION

This sketch shows a beam to column connection, the beam being wider than column and framing into web of column. In this case the beam flanges would be coped to clear column flanges. Field bolting lugs would be welded to beam and column as shown.

Field connection would be bolted.

Field welding would be horizontal across beam flanges and vertical along web if required.

ing riveted structures, to erect these welded structures in the same way. This can be done as outlined below:

Fifth: There should be no punching of heavy pieces.

Sixth: Have as few of the parts come to the fabricating mill as possible, shipping most of the steel direct to the job.

Seventh: Erect several floors by bolting them, as is done when riveting, and follow this up some distance away by the welding. In this way two things will be accomplished—there will be no blinding of the steel workers by the arc, and there will be no dropping of hot metal on to the men who are erecting the steel.

Eighth: Use large electrode and large currents.

Ninth: Eliminate scarfing on all sections ½ in. or less, and scarf only partially on sections heavier than this. Penetration in excess of ¼ in. can be obtained if the proper size electrode and proper heat are used.

Tenth: Carefully inspect the finished welding and technique of the operator. There has been for some time the feeling that proper inspection of a weld is impossible. As a matter of fact, the external appearance of a weld will tell just as completely whether it has been properly done as the external appearance of the steel itself. It seems to me self-evident that there is no necessity of inspection going further than that. There is just as much difference between the appearance of a good weld and a poor weld as there is between steel and wood, and any man of average intelligence can, with a few hours training, estimate the strength of a weld fully as closely as anyone can with any training tell from visual inspection that the strength of the steel itself is.

Eleventh: The most important thing in structural steel welding is the elimination of the difficulties in erection. I am showing by illustrations a number of schemes for making the various kinds of connection so that the workers who now generally erect riveted buildings rapidly and easily may erect the welded buildings with the same ease. These suggestions are not made with the idea that they are the last word on the subject—they are given merely to give a suggested method which has been proven feasible. It is safe to say that if these schemes are followed that there will be no greater difficulty in erecting a welded building than erecting a riveted building.

An Interesting Thesis on Structural Arc Welds*

A COPY of an unusually practical study, by Boris M. Shimkin, on the strength of arc welds in structural connections, has been received. Mr. Shimkin, who is a student member of the American Welding Society, prepared this study as a thesis for the degree of Master of Science in Civil Engineering at the University of California, May, 1928. The paper gives the results of laboratory research on the average welding work of local shops. Three standard makes of steel, and five brands of 5/32 in. bare wire electrodes were employed.

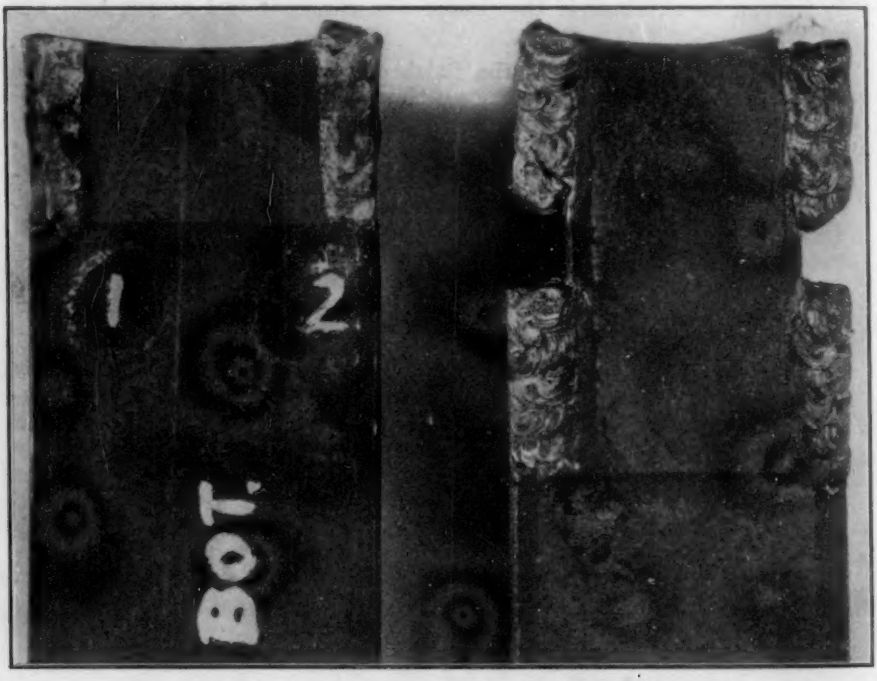


FIG. 1. STRAIN LINES ON LONGITUDINAL SHEAR SPECIMEN

The report is too lengthy to be reprinted in full in the Journal, but the fact that the specimens were prepared on a commercial rather than a laboratory basis warrants the following partial summary, whose results will be seen to agree quite closely with those previously known to the industry.

Thus, 31 specimens of butt-weld on $\frac{3}{8}$ and $\frac{1}{2}$ in. plate developed tensile strengths per square inch of from 40,000 to 56,000 lb with an

*An abstract of a thesis prepared by Boris M. Shimkin, University of California.

average of 45,610 lb. per sq. in. Welds made by a beginner in the art of welding varied from 30,700 to 47,600 lb per sq. in.

Fourteen specimens of ⅜ to ½ in. fillet-weld, disposed parallel to line of pull, developed shear strengths per linear inch of from 7520 to 11,700 lb. with an average of about 10,000 lb. per linear inch. The corresponding ultimate strength varied from 22,200 lb. per sq. in. to 33,700 lb. per sq. in. In these specimens the work of the beginner had improved.

Fourteen similar specimens, with fillets disposed normal to line of pull, developed corresponding strengths of from 9820 to 15,250 with an

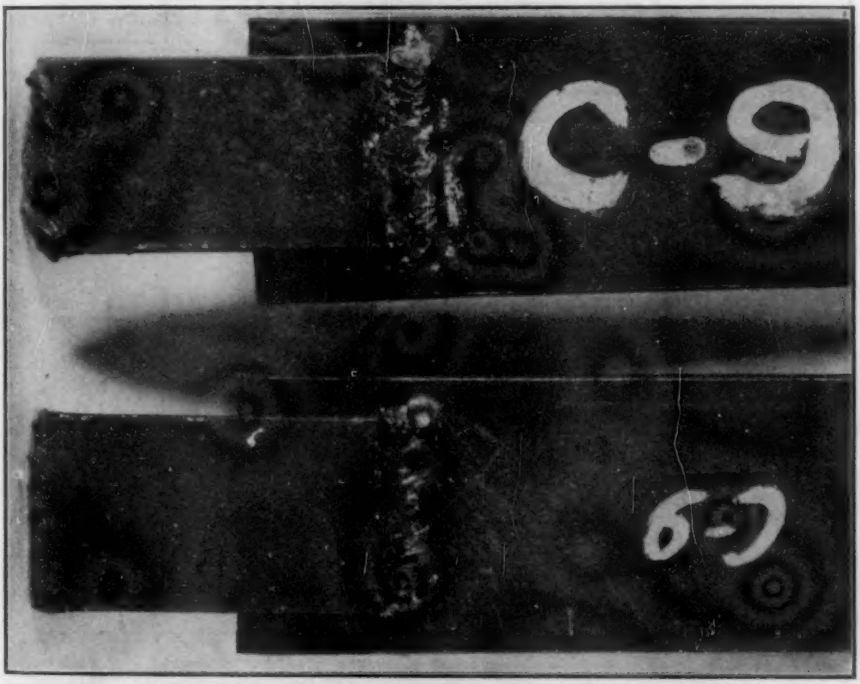


FIG. 2. STRAIN LINES ON CROSS SHEAR SPECIMEN

average of about 12,200 lb. per linear inch. The average increase in strength of this form of joint over the parallel fillet form being 23.4 per cent. In the above figures the work of the beginner is eliminated. The yield point for the welded specimens as indicated by the drop of the beam method averaged 82.2 per cent of the ultimate strength. The ratio of shear to tensile strength averages about 0.61 for parallel shear and 0.80 for longitudinal shear.

The report includes tests for bending, torsion, fatigue and hardness, together with tests on entire welded beams and columns of light construction, and a bibliography of the subject.

We reproduce a portion of the study dealing with Strain Distribution, noting that Mr. Shimkin uses the terms "longitudinal" and "cross" ratio of shear to tensile strength averages about 0.61 for parallel shear and 0.80 for longitudinal shear.

Strain Distribution in Welded Specimens

On the tension specimens, Tl-19, 20, 21, 34, 35, 36, 37, 38, the strain lines developed during the tension tests can be seen very clearly. These strain lines appeared very faintly on each specimen at about half the

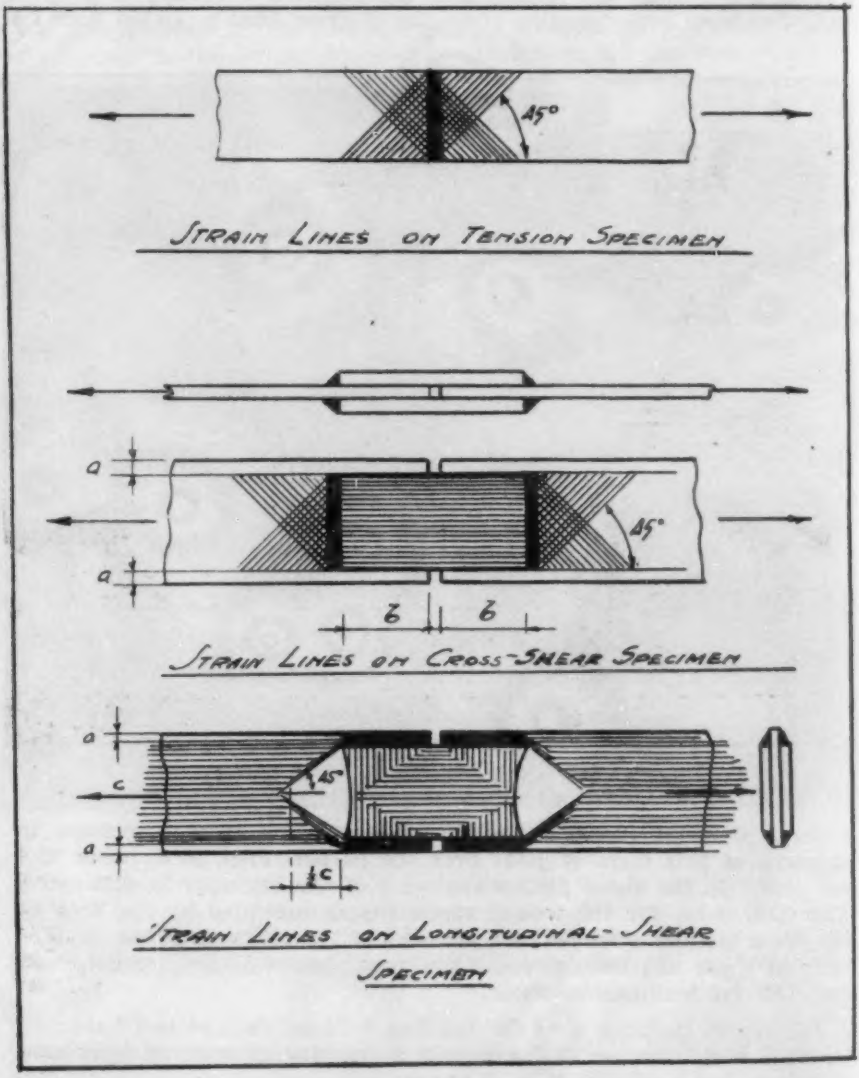
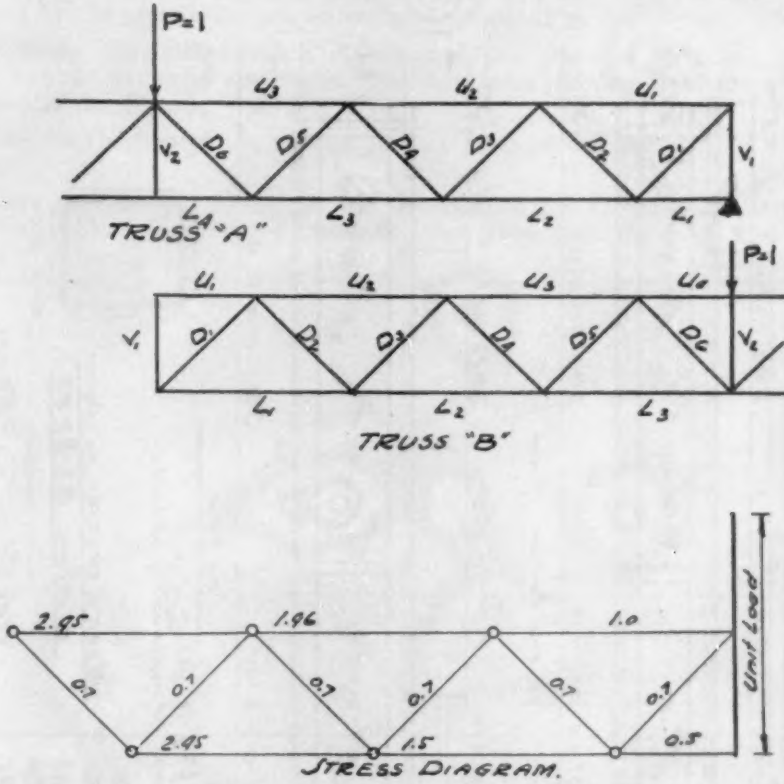


FIG. 3

ultimate load, and then increased with the load. They inclined at about 45 deg. to the axis of the specimens and began directly from the weld, as shown on Sketch 1 (Fig. 3).



TRUSS "A"				TRUSS "B"			
MEMBER	STRESS	MEMBER	STRESS	MEMBER	STRESS	MEMBER	STRESS
U_1	-0.5	$D_{1,3,5}$	+0.7	U_1	0	$D_{1,3,5}$	-0.7
U_2	-1.5	$D_{2,4,6}$	-0.7	U_2	-1.0	$D_{2,4,6}$	+0.7
U_3	-2.95	V_1	-0.5	U_3	-1.96	V_1	0
L_1	0	V_2	0	U_4	-2.95	V_2	+1.0
L_2	+1.0			L_1	+0.5		
L_3	+1.96			L_2	+1.5		
L_4	+2.95			L_3	+2.95		

FIG. 4

Strain distribution in cross-shear specimens after failure can be seen very clearly on the enlarged photograph of C-9 (Fig. 2). Here a modified tension case may be observed: the tensile stresses are trans-

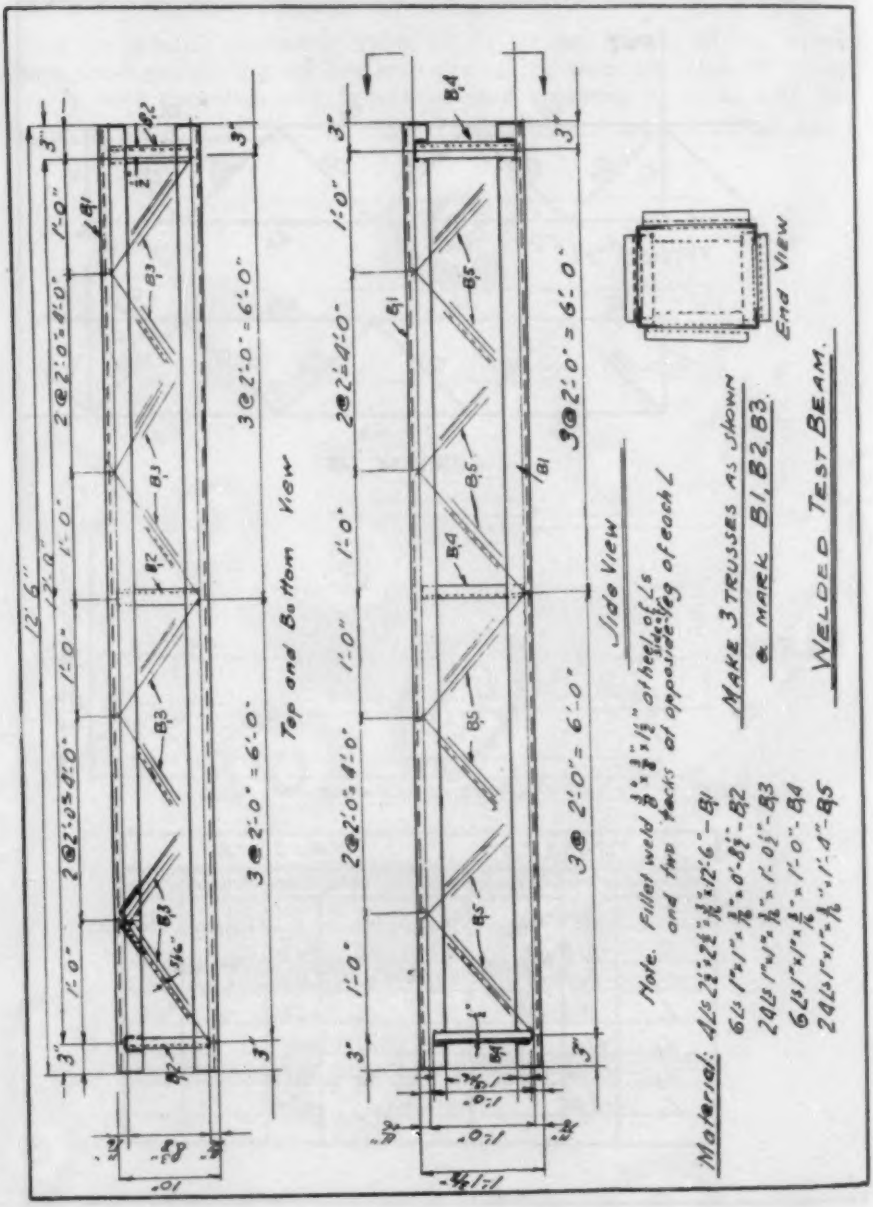

Top and Bottom View
Side View
End View
Note. Fillet weld ... and two backs of opposite leg of each L
Material:
Make 3 trusses as shown
& mark B1, B2, B3.
Welded Test Beam.

Fig. 5

ferred from the parent metal through the welds to the two cover plates, and then again through the welds to the next parent plate.

The specimen appears as though it had been held in a jaw, the width of which equals the width of the cover plate. Therefore, the parts "a" and "b," as shown on Sketch 2 (Fig. 3) carry no stress. This is clearly shown by the smooth surface on the photograph (Fig. 2).

A more complicated strain distribution and transfer happened in the longitudinal shear specimens. The specimens showing this best are presented in Fig. 1.

The distribution of the strains on both sides of the specimen is the same.

Here stresses are uniformly distributed upon the parent plate until within one-half the width of the small cover plates from the weld, where

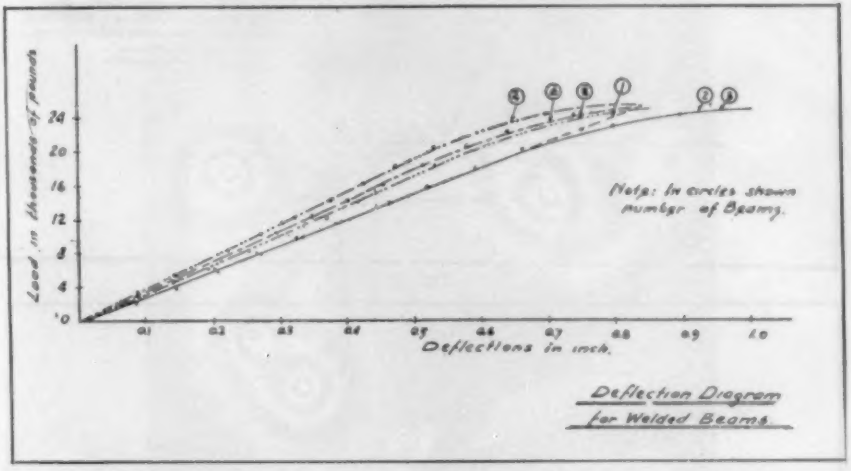


FIG. 6

the stress lines suddenly change direction and under a 45 deg. angle, transfer the stress to the weld.

Then, with an intensity proportional to the length of the weld, they act through the cover plates and in the same order follow toward the next parent plate (See Figs. 1 and 3).

Under the stress produced near the weld, the parent and cover plates changed their straight edges to a concave shape.

Without additional investigation, the presence of the strainless parts of the parent plates ("a", Sketches 2 and 3, Fig. 3) cannot be explained.

By a comparison of Sketches 1 and 2, and identity of strain distribution can be noticed. The only difference is in the length of the weld (tension) and cover plates (cross-shear). This similarity undoubtedly affects the average efficiency of the weld in tension and cross-shear, which have the same percentage of efficiency.

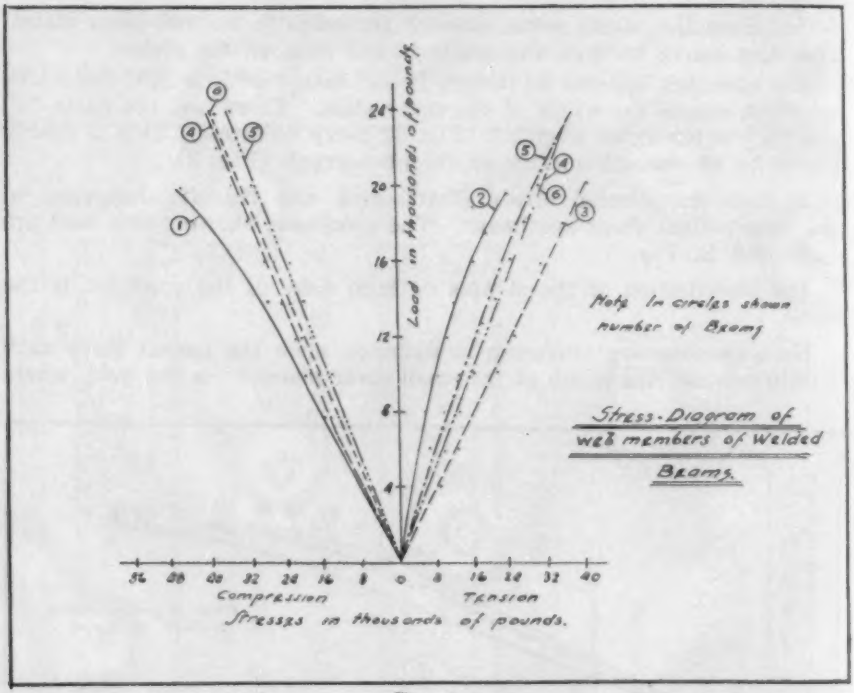

Load in thousands of pounds
24
20
16
12
8
4
Nos. in circles shown number of Beams
Stress-Diagram of web members of Welded Beams.
Compression
Tension
Stresses in thousands of pounds.

FIG. 7

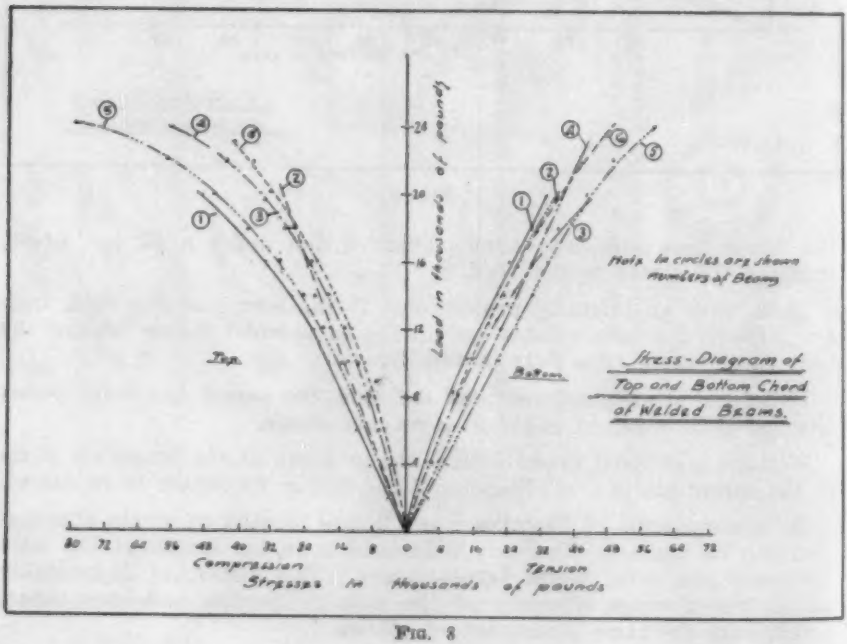

Load in thousands of pounds
24
20
16
12
8
4
Nos. in circles are shown numbers of Beams
Top.
Bottom.
Stress-Diagram of Top and Bottom Chord of Welded Beams.
Compression
Tension
Stresses in thousands of pounds

FIG. 8

There is also given an abstract of Part II of Mr. Shimkin's thesis—"The strength of arc welds in structural connections."

Tests of Beams

Design of Beams. Two types of beams were used in these tests—box-beams and truss-beams. Geometrical dimensions for both beams are the same, and the stress diagram for the unit load at the center of the beam is drawn on Fig. 4, where coefficients for stresses in the truss members are shown.

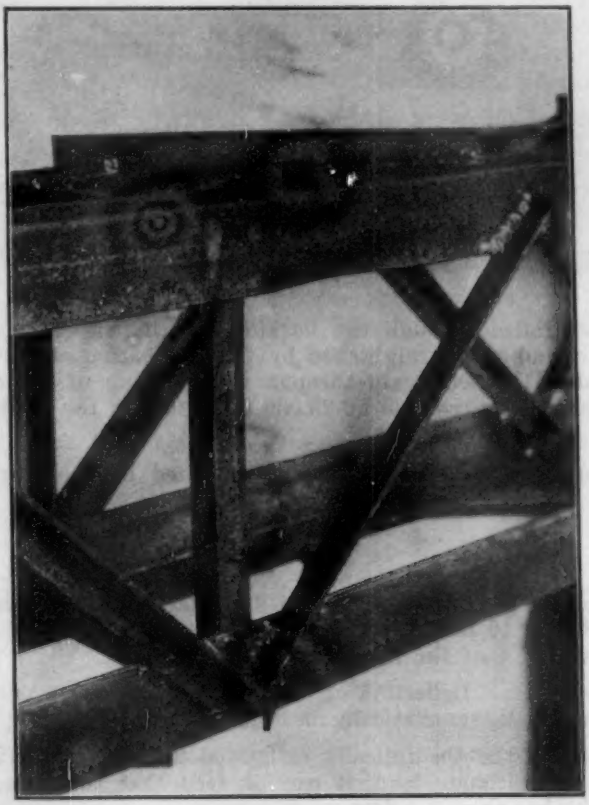


FIG. 9. FAILURE OF WELDED BEAM IN BENDING TEST BY BUCKLING OF UPPER CHORD. NOTE POSITION AND TYPE OF WELDS

Two methods of applying the load are shown there also (Truss "A" and Truss "B").

The physical dimensions and the section of some of the truss members are given in Fig. 5. The design load for failure was 20,000 lb., concentrated at the center of the beam, and the maximum chord stress based upon this load was 29,500 lb., while the maximum stress in any diagonal is 7050 lb.

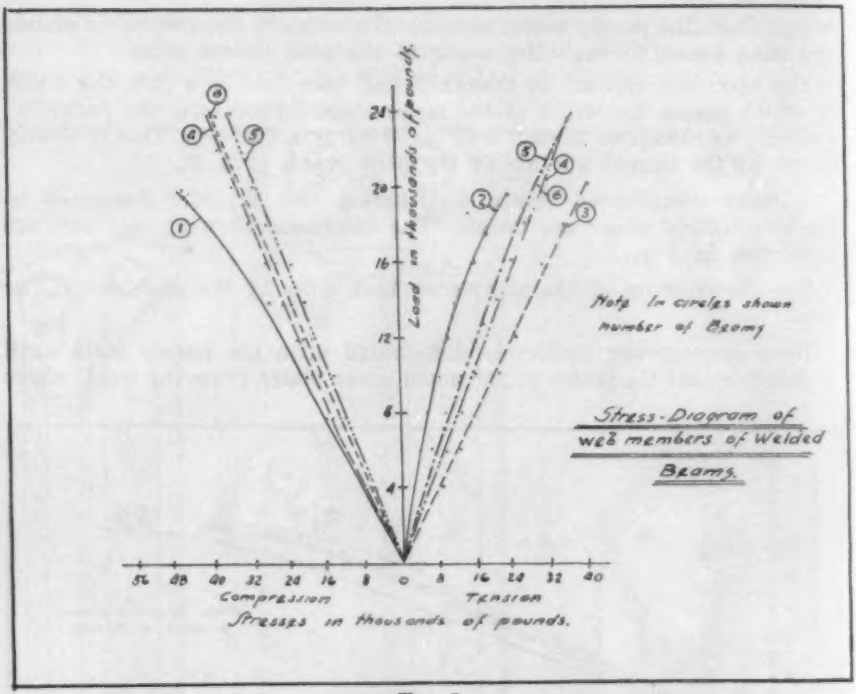
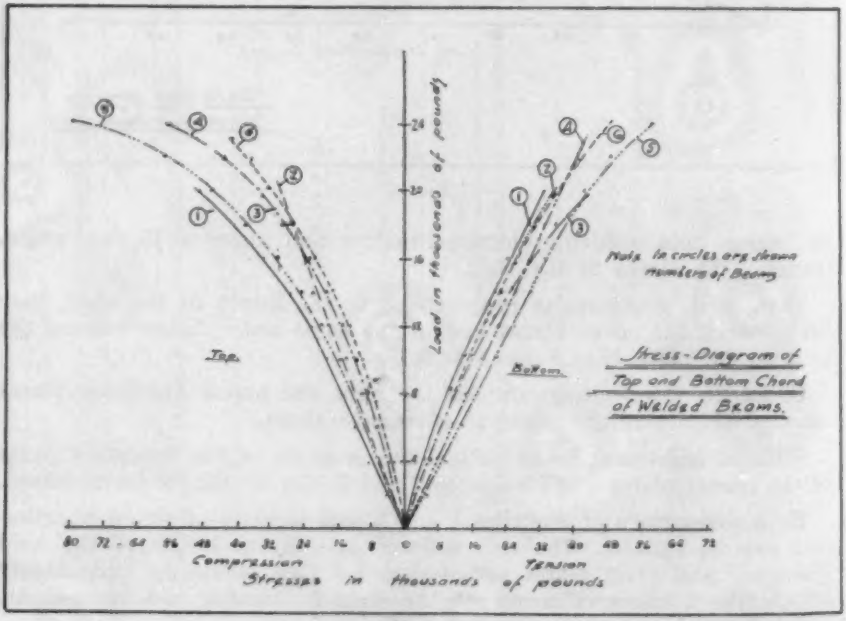

Load in thousands of pounds.
Note In circles shown number of Beams
Stress-Diagram of web members of Welded Beams.
Compression
Tension
Stresses in thousands of pounds.

FIG. 7


Load in thousands of pounds
Note In circles are shown numbers of Beams
Top.
Bottom.
Stress-Diagram of Top and Bottom Chord of Welded Beams.
Compression
Tension
Stresses in thousands of pounds

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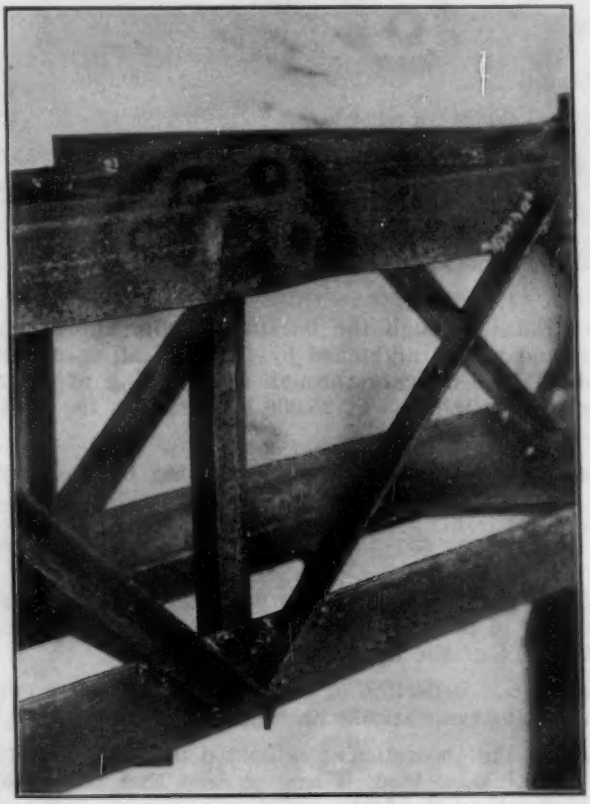

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Procedure in Tests. All beams were tested on the 200,000 lb. Olsen Testing Machine with the speed of 0.05 in. per min.

Holes, 5/32 in. in diameter, were drilled in the top and bottom chords and web members for the strain gage readings, which were taken after every 2000 lb. increment in load. Readings of the deflectometer in the middle of the span of the truss were also taken.

All data and strain gage readings are given on Figs. 6 to 8. The yield points were observed by the dropping of the beam scale, and were as follows:

B-1 and 3 ..... at 22,000 lb.
B-2 ..... at 21,000 lb.
B-4, 5 and 6 ..... at 24,000 lb.

The ultimate loads were recorded as follows:

B-1 ..... 24,500 lb, and 25,000 lb.
B-2 ..... 25,100 lb.
B-3 ..... 25,400 lb.
B-4 ..... 24,300 lb.
B-5 ..... 24,600 lb.
B-6 ..... 24,800 lb.

After B-1 failed through the buckling of the upper chord, it was turned over, and was straightened by the application of a load on the lower chord. It failed again through the buckling of the compressed web members under the load of 25,000 lb., although the welds were not injured.

All stresses in the members were calculated by the formula:

$$S = \frac{Ee}{10},$$

where $E = 3 \times 10^7$ (Modulus elasticity of steel) and $e =$ the total deformation in the 10 in. gage length. This formula was applied only up to the elastic limit of the material.

Results of Tests. Deflection of the beams and stresses under applied loads are shown diagrammatically on Figs. 6, 7 and 8.

By comparing the theoretically estimated ultimate load (20,000 lb.) and the actual ultimate load, it can be seen that the latter is about 5 per cent higher than the first.

The fracture of Beam B-1 happened through the buckling of the upper chord (Fig. 9) and is ascribed to the weakness of the vertical member (V_2). It was then decided to turn over the next beams and to test them by applying a load at the top of the middle diagonals (truss "A"—see Fig. 4). The result of these tests was better—the ultimate load increased to 25,100 and 25,400 lb., as compared with the 24,500 lb. of B-1.

Beams B-2 and B-3 failed through the buckling of the compressed web members (Fig. 10). Beams B-4, 5 and 6 failed through the buckling of the upper chord of trusses (Fig. 11).

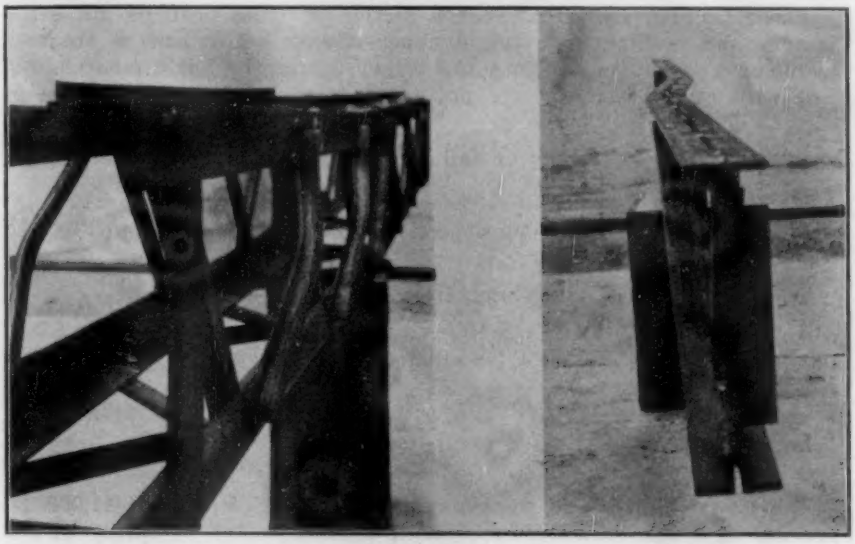


FIG. 10. FAILURE OF WELDED BOX-BEAM (B1, 2 AND 3) BY BUCKLING OF COMPRESSED WEB MEMBERS

FIG. 11. FAILURE OF WELDED TRUSS BEAM (B4, 5 AND 6) BY BUCKLING OF UPPER CHORD

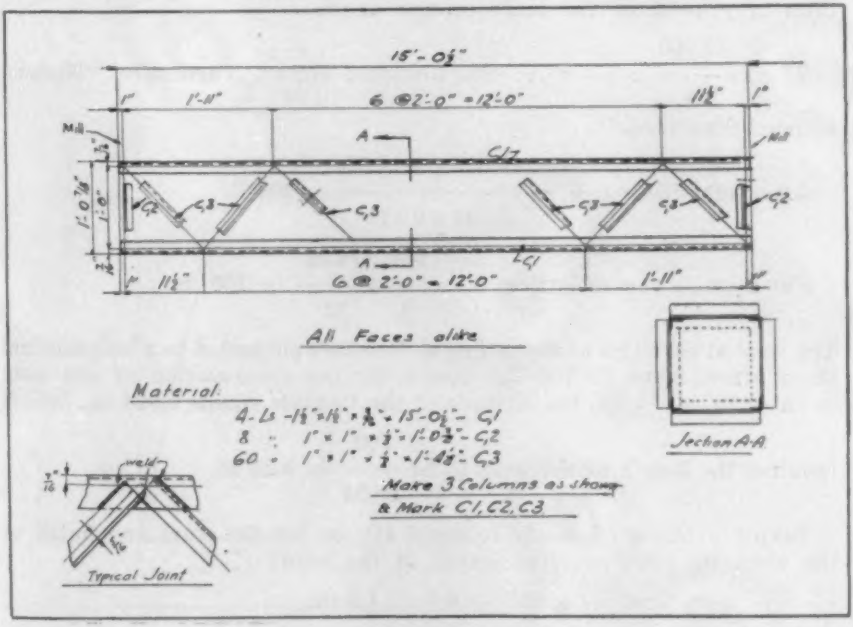


FIG. 11

These failures show that such a section of truss beam is not satisfactory and requires more rigid upper chords, which can be obtained by using unequal angles with the larger leg of the angle outstanding. The ends of the beams were prevented from twisting by the use of special clamps.

In these tests no injury or failure of the welds could be noticed.

Tests of Columns

Design of Columns. A square section of column (as shown in Fig. 11) was taken.

The total length of the column from end to end—15 ft. ½ in.

Four angles—1½ x 1½ x 3/16—with the area equal to 4 x 0.53 = 2.12 sq. in. and $I_{r-1} = 76.76$ in. Radius of gyration, r = 6 in. and ratio 1/r = 30.

Leg of column: Ratio $1/r = \frac{24}{.29} = 83.$

The stress allowed by the American Bridge Company is 11,000 lb. per sq. in. The ultimate load, based upon a factor of safety of 3.5 equals 3.5 x 11,000 x 2.12 = 81,500 lb.

Stress in each lattice angle is: $S = \frac{V}{2} \times \frac{1'}{b}$, where V is the total shear, 1′ the length of the lattice angle, and b the width between the lines of gravity of the main column angles.

$V = \frac{15{,}000}{1/r} \times \frac{r}{c} \times A$ (See Johnson, Bryan, Turneaure, "Modern Framed Structures").

After substituting, $V = \frac{15{,}000 \times 6 \times 2.12}{30 \times 6.44} = 990$ lb.

For a single row of lattice: $S = \frac{990}{2} \times \frac{16.92}{12} = 700$ lb.

The weld at each end of the lattice is therefore subjected to a longitudinal shear stress equal to 700 lb. Assuming the cross-section of the weld to be ⅜ in. by ⅜ in., the altitude of the triangle equals 0.094 in., which requires the length of the weld to be $\frac{700}{0.094} = 0.25$ in.

Taking a factor of safety to equal 4½ in. for the start and finish of the weld, the total required length of the weld:

$$w = 4 \times 0.25 + 0.5 = 1.5 \text{ in.}$$

For the prevention of twisting of the member, 0.5 in. tack on the

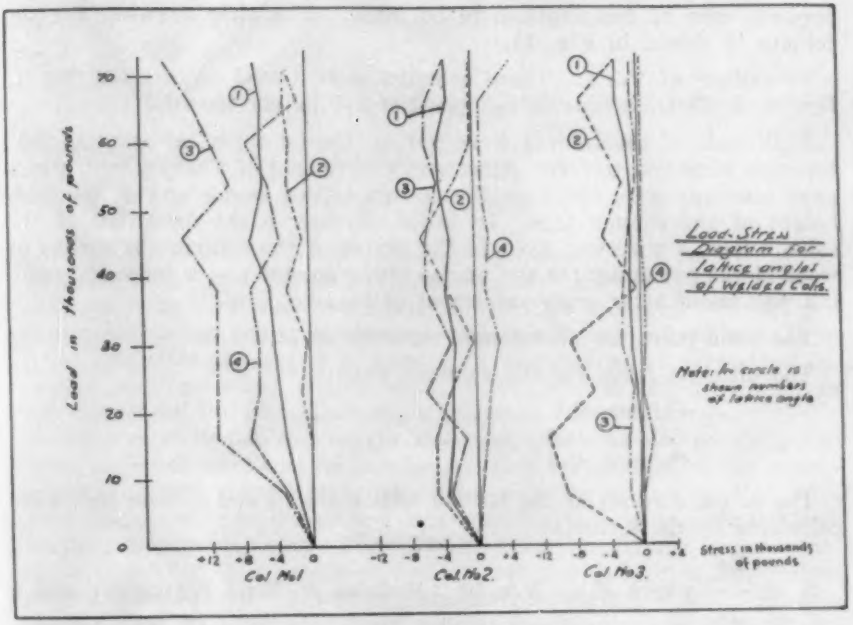

Load in thousands of pounds
70
60
50
40
30
20
10
0
Load. Stress Diagram for lattice angles of Welded Cols.
Note: In circle is shown numbers of lattice angle
Col No1
Col No2
Col No3
Stress in thousands of pounds

FIG. 12

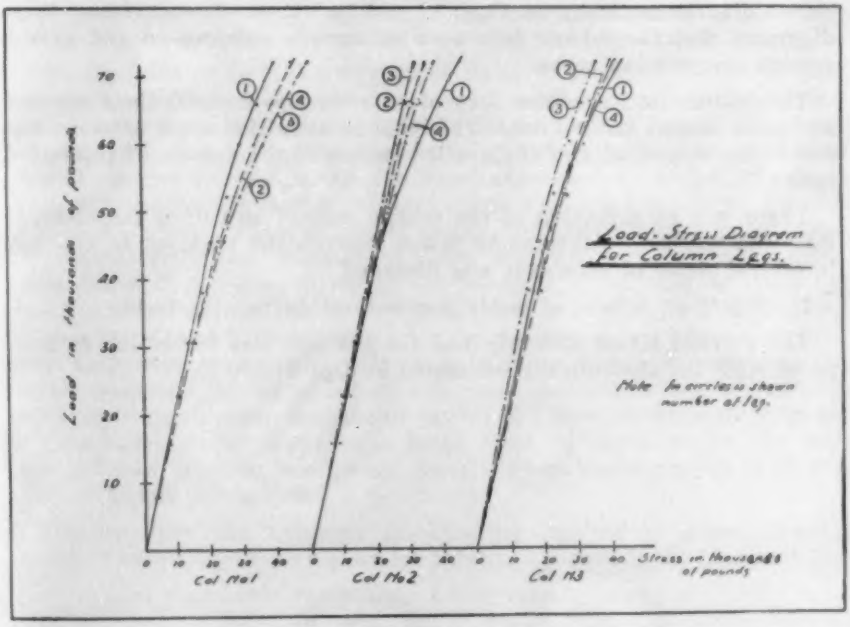

Load in thousands of pounds
70
60
50
40
30
20
10
Load. Stress Diagram for Column Legs.
Note In circles is shown number of leg.
Col No1
Col No2
Col No3
Stress in thousands of pounds

FIG. 13

opposite side of the angle is to be made. The shop drawing for the column is shown in Fig. 11.

Procedure of Tests. These columns were tested on the 500,000 lb. Hydraulic Test Machine with a speed of 170 lb. per second.

Both ends of the column were put on special spherical seats so that the ends were free to turn. After every increment of 8000 lb. load, strain gage readings were taken on the bottom lattice angles and at the mid-height of the column legs. In order to observe the deflection of the column legs, a wire was fixed in the center of the columns by means of wood blocks put under the end angles of the column and a deflection reading was taken after every increment of load.

The yield point for all columns occurred at 72,000 lb.

The ultimate loads for the columns were:

Column C-1	86,150 lb.
Column C-2	76,950 lb.
Column C-3	89,160 lb.

The actual stresses at the bottom lattice angles and column legs were calculated by the formula:

$S = \frac{Ee}{10}$, where $E = 3 \times 10^7$ (Modulus of Steel Elasticity) and e = the total deformation in a 10 in. gage length.

Results of Tests. The stresses corresponding to the applied load are shown diagrammatically on Figs. 12 and 13. It can be noticed on these diagrams that the column legs were uniformily compressed and gave a smooth compression curve.

The bottom lattice angles very often suddenly changed their stresses and gave jagged stress-lines. This change of lattice angle stresses was due to the eccentricity of the applied loads and the defects of the milled ends.

There was no deflection of the middle column legs until the ultimate load was reached. All columns failed through the buckling of the legs in several places at once as it was designed.

No injury or failure of welds was noticed during the tests.

The average actual ultimate load for the test was 86,000 lb., as compared with the theoretically estimated load of 81,500 lb.

Present Status of Welding Steel Buildings by Electricity*

FRANK P. MCKIBBEN†

ARTICULATION or joining together by electricity of various members in a steel building frame consists first in developing the technique of welding and then adapting it to the industry. Rarely is a manufacturing process so revolutionary as to carry an industrial field by storm, and after the art is brought to a fair degree of perfection the problem then arises of incorporating it in various factories with as little disturbance as possible to the established order of things.

Electric welding has been so far developed that it is now recognized as a safe and economical tool for fabricating steel structures. It has passed the experimental stage. It can be used with the assurance that with proper supervision in design and workmanship, safety can be obtained. One need only point to over fifty existing welded buildings to show that this new method is a safe one, because not one failure in any welded building has occured. Moreover, designing engineers now have available sufficient data, secured from reliable sources, to enable structural details to be designed with confidence. Numerous tests have been made by colleges, governmental bureaus and industrial organizations, and these, together with the large number of existing welded structures, indicate that the problem of securing safe structures need cause no worry.

The opportunity immediately before us is to acquaint architects and engineers with the possibilities which welding offers in eliminating noise and reducing costs in the construction of steel building frames. Elimination of noise due to riveting hammers operating in thickly populated districts is very important and well worth striving for. Indeed, if necessary, it is worth paying for. Interference with office buildings by unnecessary noises is a real economic factor; difficult generally to evaluate but real nevertheless. Recently a judge of a higher court in Pennsylvania found it necessary to order the cessation of riveting on a nearby steel building frame so that he might continue the Court Session. Again, while a large steel building frame was being erected in Philadelphia last year occupants of an adjacent office building found it necessary to install telephone booths to reduce the noise, and hotels nearby suffered great loss in patronage because of riveting, I have no accurate data as to this latter item, but if in a large hotel 50 rooms at $4 per day remain vacant because of noise the monetary loss would amount to 50 x 4 x 30 = $6,000 per month.

Another deterring influence in adapting welding in shops already equipped with the ordinary tools for fabricating steel is the idea that the

*Paper to be presented at Fall Meeting, A.W.S., October, 1928.
†Consulting Engineer, General Electric Company.

additional welding equipment is very costly, whereas the fact is that such shops can install at very little expense sufficient welding equipment to shop weld the steel for an ordinary building. Electrical machinery required in field welding is heavier and larger than that required in field riveting if in the latter case rivets be hand driven, but is no greater than that required when rivets are driven by compressed air. At the West Philadelphia Welded Building of the General Electric Company containing 987 tons of steel, only two single operator motor driven welding sets were used most of the time and for awhile only one was used. This meant two welders at the most.

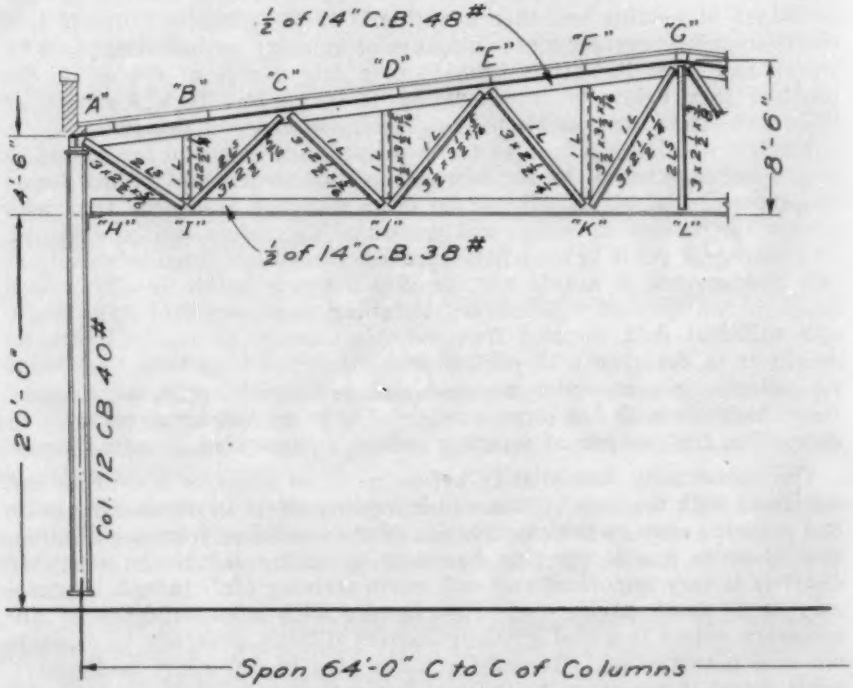


FIG. 1. ONE HALF ARC WELDED TRUSS—GENERAL ELECTRIC BUILDING, BRIDGEPORT

The training of designers, draftsmen and welders is relatively simple and need cause managers of steel fabricating shops little concern. The best way to begin is to begin. I find that designers and draftsmen grasp the elements of design quickly.

Welding and the Building Codes

So far as building codes are concerned welding could not have chosen a more appropriate time to introduce itself, because several cities including some of the largest and most important are revising their codes to change from the 16,000 to the 18,000 lb. unit stress basis. New York

Philadelphia, Chicago and Pittsburgh are among the larger cities now engaged in code revisions.

The American Welding Society's Committee on Building Codes has undertaken the drafting of a code and until they report, there are three ways for city or state officials to proceed with their own revisions.

First; merely state in the new code that—

"Welding may be substituted for or used in connection with those methods already prescribed in the building code of the City of ..... for connecting together the various beams, girders, columns, trusses and other parts of steel frames for buildings; provided, that the welding be done by competent workmen in accordance with designs and under supervision of a competent engineer or architect skilled in this work, and under regulations or specifications now or hereafter recommended by the

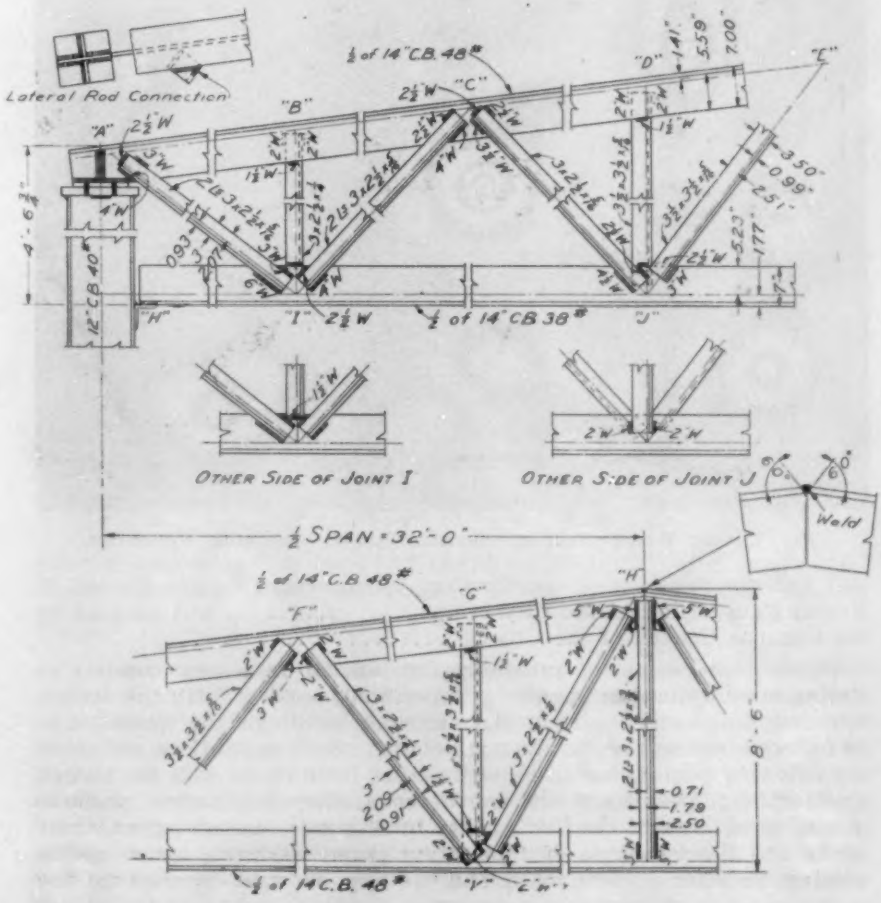


FIG. 2. DETAILS OF ARC WELDED TRUSS—GENERAL ELECTRIC BUILDING, BRIDGEPORT

American Welding Society and on file in the office of the Bureau of Building Inspection of the City of ....."

Second; instead of the general clause above noted a new code may state—

"Welding may be substituted for or used in connection with those methods already prescribed in the building code of the City of ..... for connecting together the various beams, girders, columns, trusses and other parts of steel frames for buildings; provided, that the welding be done by competent workmen in accordance with designs and under supervision of a competent engineer or architect skilled in this work,

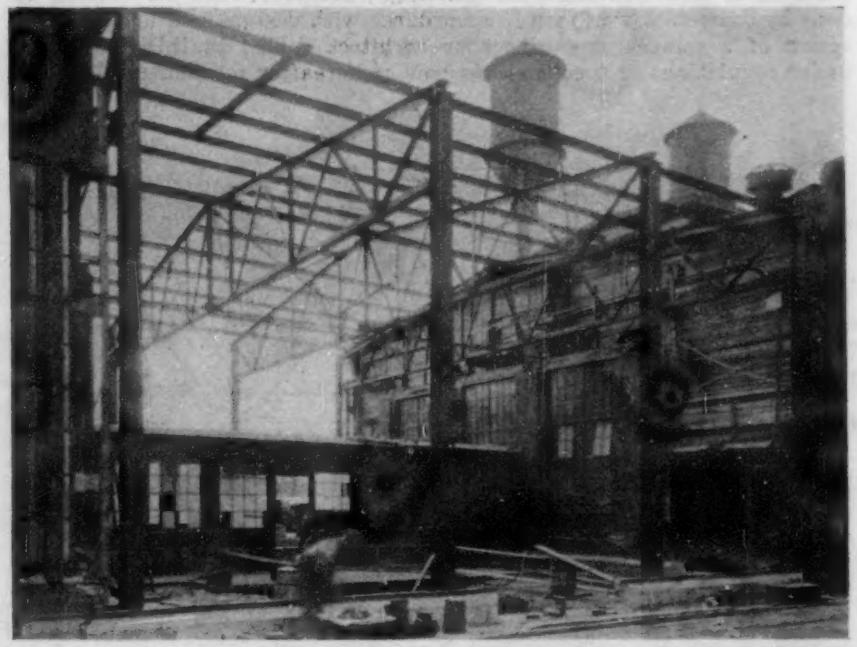


FIG. 3. ARC WELDED TRUSSES—GENERAL ELECTRIC BUILDING, BRIDGEPORT

and under regulations or specifications recommended by the Bureau of Building Inspection of the City of ..... and adopted by the Common Council of the City of ....."

Third—this method of providing for welding in a code consists in stating specifications or regulations specifically setting forth the design, fabrication and erection of steel frames for buildings, the technique to be followed both in electric and gas welding. Such regulations will cover the following points in addition to those set forth in the code for riveted construction: Definitions, the use of bolts, shop fabrication, preparation of steel, current density, quality of electrode, use of lap and butt joints and the technique of fabricating them, welding apparatus, gas welding, tests for welders, oiling and painting, allowable stresses for use in design.

Of the three methods of providing at present for welding in code revisions the first two are simple and more flexible. While the third method can be made fairly specific it is open to the objection that in the early applications of welding to building construction frequent changes in details may be desirable and might be difficult to make after the specifications are once adopted by a governing body such as a municipal common council or a state legislature.

I think the practice of granting special permits or so called "technical violation permits" is unwise. If a type of construction is economical.

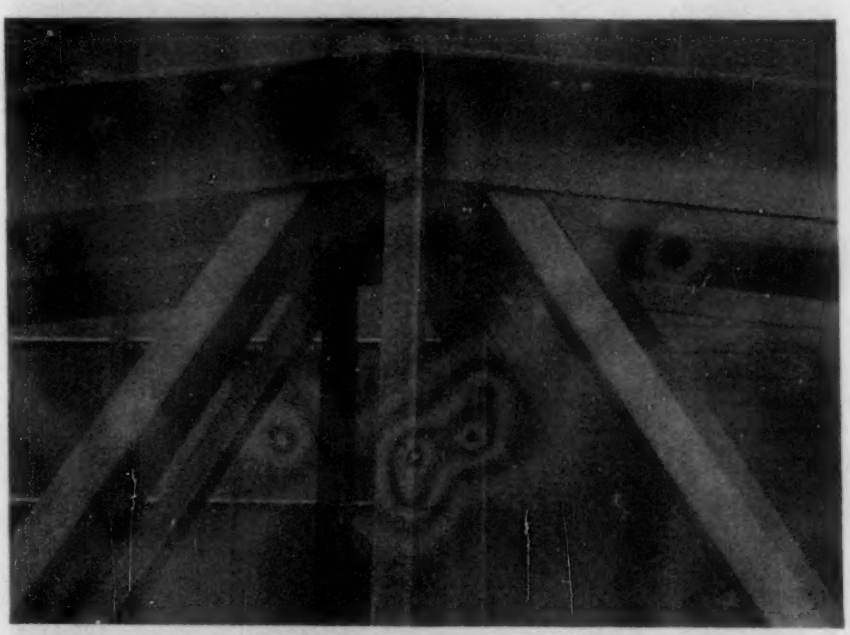


FIG. 4. CENTER TOP CHORD JOINT AND TOP CHORD SPLICE. ARC WELDED TRUSS—GENERAL ELECTRIC BUILDING, BRIDGEPORT

safe and desirable it is good and should be permitted; if it is not sufficiently developed to give assurance in safety it should not be allowed.

Flexible Versus Inflexible Codes

In this connection it is interesting to observe that so far as adoption of new methods or new materials are concerned codes may be classified into flexible or inflexible. Inflexible codes are those which make no provision for new methods or new materials, state specifically or by implication how a work is to be accomplished, and leave no freedom of action vested in the administrative officers whose duty it is to carry out the provisions of the code. Codes of this nature are unnecessarily severe in many cases, and either cause the administrative officers to violate the ordinance by granting permits when the ordinance becomes clearly out-of-date, but still in force, or works hardships on manufac-

turers of new materials and penalizes owners by prohibiting them from using newer and more economical types of construction. Well do many of us remember when reinforced concrete buildings were permitted by some city building departments long before their codes had been revised to admit this type of construction, while other cities inflicted penalties on their tax payers by excluding it.

A flexible code on the other hand contains a clause which makes it possible for the administrative officer to admit new methods. Obviously

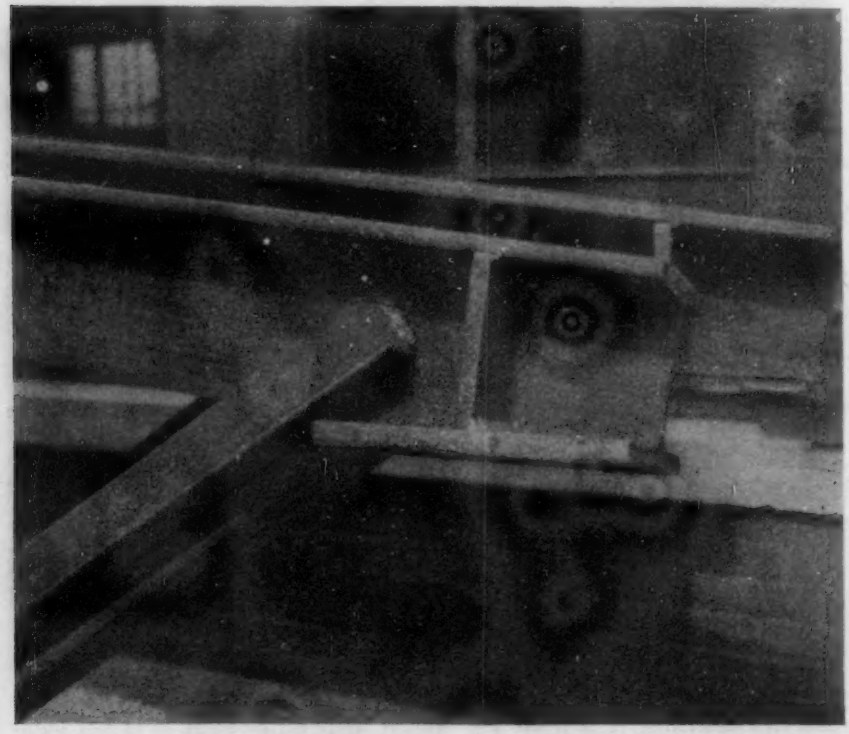


FIG. 5—END BEARING FOR ARC WELDED TRUSS—GENERAL ELECTRIC BUILDING, BRIDGEPORT

some checks must be thrown around such a scheme so that all changes are publicly made and applied to all persons alike. The following section illustrates a clause giving flexibility yet surrounded by sufficient safeguards:

"Whenever it is desired to use new materials, or materials not specified in this code, application therefor shall be made to the Board of Building Commissioners in writing, stating in detail the materials and the manner and construction in which they are to be so used. The person or persons seeking to use such new materials shall give to the said board upon its

request, therefor, such information and tests in connection with the nature and use of such proposed new materials as the said board require."

Some New Welded Buildings

Trusses in General Electric Company's Bridgeport (Conn.) Plant

The steel for this structure, Fig. 1, consists of four welded trusses, Fig. 2, with spans of 64 ft.-0 in. c to c of steel columns. The trusses are braced with steel purlins, one bay of lateral bracing in plane of the top chords, an angle tie connecting the lower chords at their centers, and a

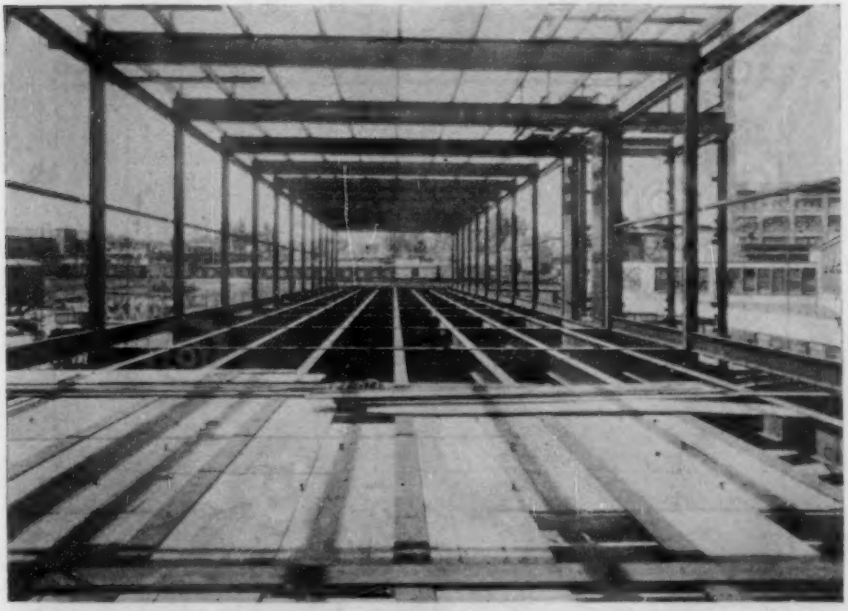


FIG. 6. SECOND FLOOR ARC WELDED BUILDING 36, PITTSFIELD WORKS. LOOKING NORTH

sway frame at center of span. The structure connects two existing buildings, and covers an area of approximately 66 ft. x 42 ft., Fig. 3.

Structurally there are four interesting features; (a) use of tee sections for top and bottom chords; (b) absence of lattice bars and gusset plates; (c) top chord splice, (d) the truss end bearing.

The top chord consists of a tee made by cutting a 14 in.—48 lb. beam lengthwise along the center of its web, and the lower chord is a tee made similarly from a 14 in.—38 lb. beam. Gussets were avoided by welding the verticals and diagonals directly to the webs of these tees.

Inasmuch as the top chord slopes downward either way from the center of span to conform to the existing sloping roof, it had to be spliced at the center. This splice consists of a single Vee butt splice in the flange of the tee, the angle of the Vee being about 75 deg. The stem is spliced on each side by the $2\frac{1}{2}$ in. x $\frac{3}{8}$ in. leg of an angle which constitutes the central vertical web member, Fig. 4. Fig. 2 shows

the unequal lengths of fillet welds connecting the end diagonal consisting of two 3 in. x 2½ in. x 5/16 in. angles; the long fillet being at the back of the angle and the short fillet along the outer edge. This is in accord with theoretical requirements.

The bearings for the truss are at the ends of the top chord where it rests upon the columns, and to stiffen the vertical stem or web of the top chord a stiffener plate 4 in. x ⅝ in. is welded to each side to the web, to the underside of flange and to the 10 in. x ¾ in. x 9 in. bearing

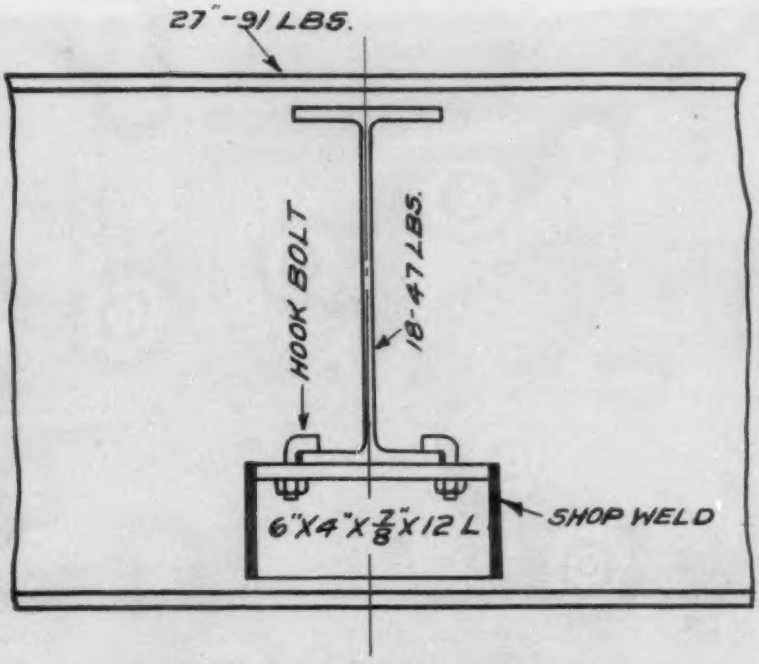


FIG. 7. FLOOR BEAM SEATS ON 27 IN.-91 LB. GIRDERS TO SUPPORT 18 IN.-47 LB. FLOOR BEAMS, BUILDING 36, PITTSFIELD

plate, Fig. 5. Stiffeners of this kind should be fitted at their lower ends to transfer their share of the reaction to the top chord web. Otherwise the amount of stress each can carry is limited by the strength of the fillet at the bottom of the stiffener.

To secure a large tee section of the kind used here it is necessary to cut lengthwise an H section or a beam. This may be done either by flame cutting the web with a gas torch or by punching it. In this case a long but thin punch was used. When beams of this sort are burnt there is a tendency for the two cut sections to curl, especially when the torch is applied continuously from one end. If, however, the torch be used

intermittently, burning slits alternately leaving solid metal between this difficulty is somewhat obviated.

The triangular fillets subjected to longitudinal shear were designed on a safe working stress of 11300 lb. per sq. in. shearing in the throat, i.e., in the minimum section of fillet; and this gives for $\frac{3}{8}$ in. fillets, 3000 lb. per linear inch; for 5/16 in. fillets 2500 lb. per linear inch; and for $\frac{1}{4}$ in. fillets 2000 lb. per linear inch.

Each truss was completely welded in the shop and shipped as one piece. The only field welding consisted of four fillets each 3 in. long at the

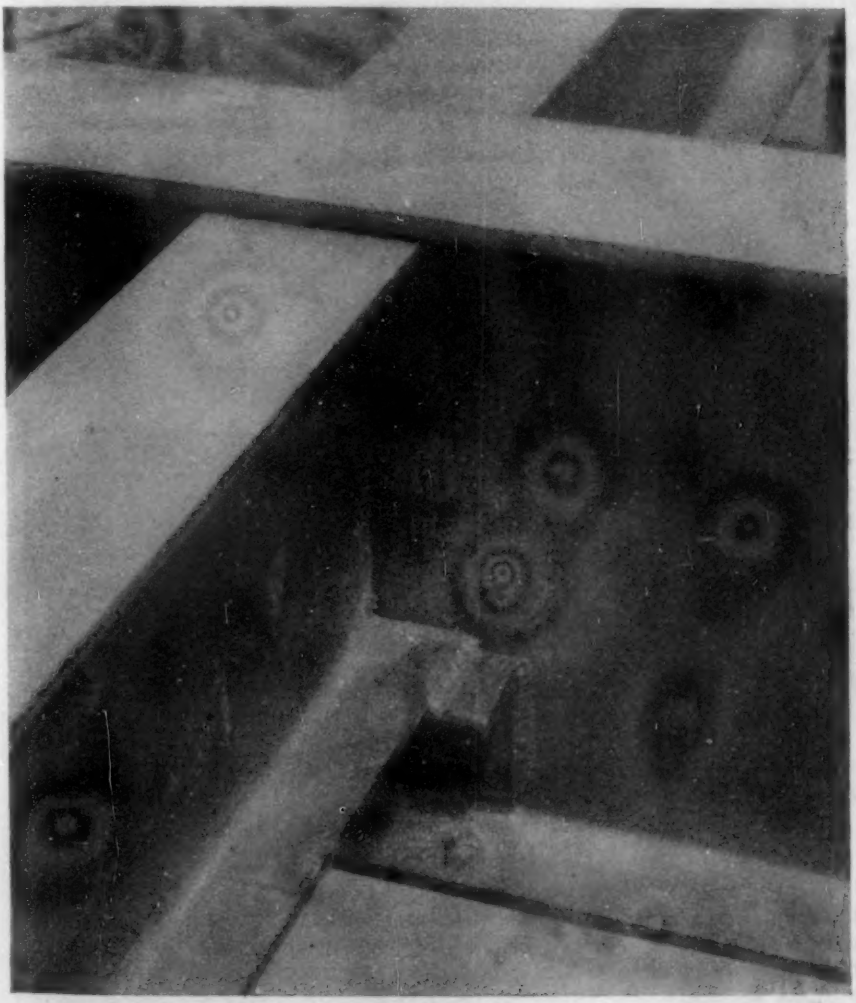


FIG. 8. TYPICAL CONNECTION FLOOR BEAM TO GIRDER, WELDED ON JOB IN ARC WELDED FRAME OF BUILDING 36, PITTSFIELD WORKS

top of each column to weld the truss bearing plate to the column cap, and two fillets each 3¼ in. long to connect each end of each lower chord to an angle bracket previously shop welded to the face of the column flange.

Beam and Column Building of General Electric Company at Pittsfield, Mass.

This factory building is approximately 42 ft. in width, 280 ft. in length with 14 bays each 20 ft., with a canopy along one side covering a loading platform.

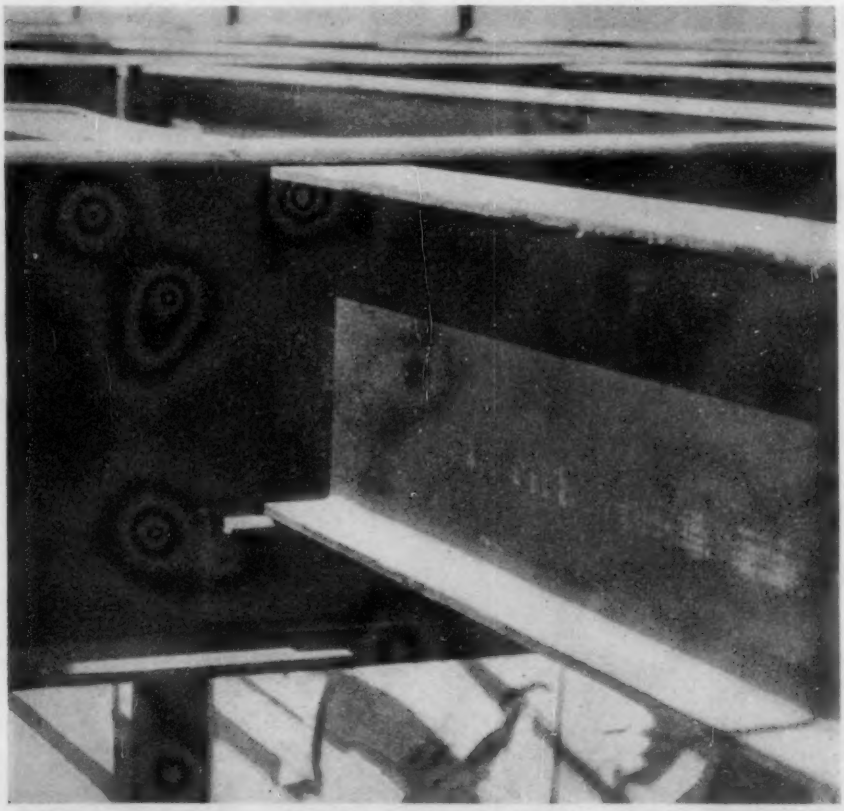


FIG. 9. TYPICAL CONNECTION, FLOOR BEAM TO GIRDER, IN ARC WELDED FRAME OF BUILDING 36, PITTSFIELD WORKS

For the most part the building consists of two stories with 20 ft. 0 in. between first and second floor levels, and with 18 ft.-0 in. clearance between second floor and the girders supporting the roof. In one bay a mezzanine floor is introduced, making the structure three stories high at that section.

A typical section, Fig. 6, shows the 9 in. channel purlins supported on

24 in.—70 lb. beams carried on top of the wall columns which are 39 ft.-1 in., on centers. The ground floor rests directly on the earth. The second main floor is of concrete 4¾ in. thick supported on 18 in. beams 5 ft.-0 in. on centers which in turn are carried on seat angles welded to the webs of the main cross 27 in.—91 lb. girders. These cross girders are continuous over a center line of columns extending from the first floor to the second floor only.

Among the very interesting details used in this structure are—(a) avoidance of any shop work on the 18 in.—47 lb. beams of the second floor thereby making it possible to ship these beams directly from rolling mill to the Pittsfield site; (b) use of angle seats shop welded to webs of 27

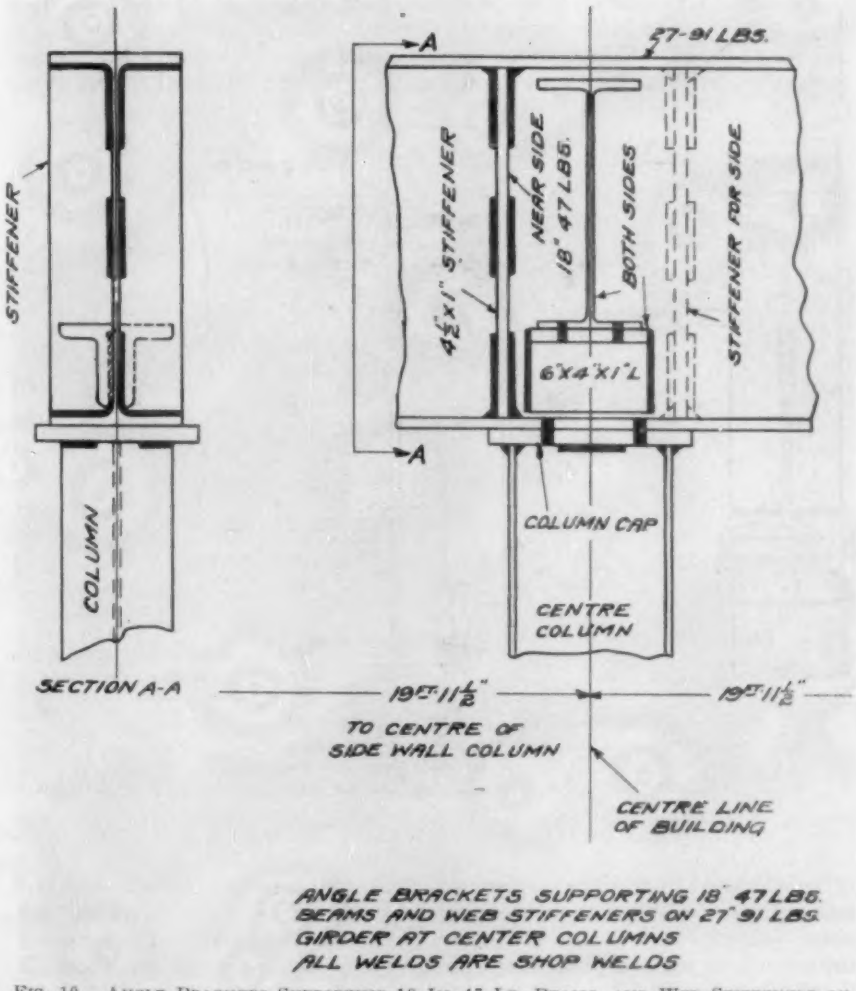


FIG. 10. ANGLE BRACKETS SUPPORTING 18 IN.-47 LB. BEAMS, AND WEB STIFFENERS ON 27 IN.-91 LB. GIRDER AT CENTER COLUMNS, ARC WELDED BUILDING—GENERAL ELECTRIC COMPANY, PITTSFIELD, MASS.

in.—91 lb. cross girders to support the second floor 18 in.—47 lb. beams; (c) 4½ in. x 1 in. web. stiffeners on 27 in.—91 lb. cross girder webs over center columns on which the girders rest; (d) supporting the 27 in.—91 lb. girders in part on angle seats shop welded to face of wall column flanges and in part by field welding the girder web directly to face of wall column flanges, the ends of the girders being milled; (e) securing transverse stiffness by field welding top and bottom flanges of 27 in.—91 lb girders directly to the wall columns; (f) supporting the sprandrel 18 in. floor channels of mezzanine and main floors on angle seats shop welded to the inner surfaces of flanges of the main wall columns.

Instead of punching holes in the bottom flanges of 18 in-47 lb. floor beams to engage bolts for connection to angle brackets on the 27 in. girder webs, hooked bolts were used, passing through holes in these angle brackets and over the 18 in. beam flanges. While this saved the handling

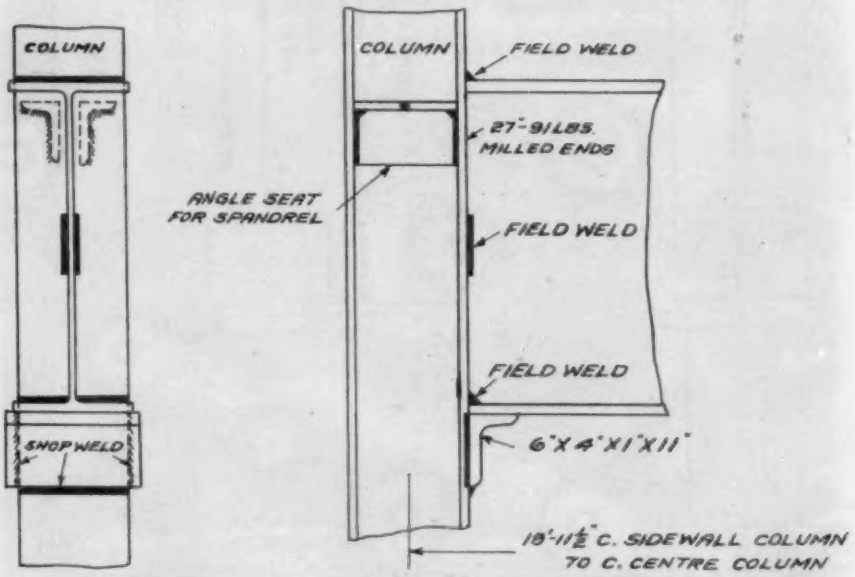


FIG. 11. CONNECTION OF 27 IN.-91 LB. GIRDER TO SIDEWALK COLUMN BY ANGLE BRACKET SHOP WELDED TO COLUMN, AND BY FIELD WELDING OF GIRDER TO COLUMN FLANGE

of floor beams in the shop, I prefer a more positive connection, however, and believe through bolts both for erection and for subsequent use are better. Fig. 7 shows the connection as made. It consists of a 6 in. x 4 in. x ⅞ in. or 1 in. x 12 in. angle shop welded to the floor beam web with 6 in. of ⅜ in. fillet at each end of the angle to take the reaction from the 18 in. beams.

The 4½ x 1 in. stiffeners at centers of 27 in. 91 lb. girders are spaced one on each side of the girder in order that the center 18 in. 47 lb. floor beam may be swung laterally into position. These stiffeners assist the lower flange in transfering the central reaction to the web, Fig. 10.

Milling the ends of the main 27 in. 91 lb. cross girders is somewhat unusual but not only aids in lining up the buildings but permits field welding to be done at contact of girder web and flanges with the face of column flange. In the lower flange of each 27 in. 91 lb. girder two field bolts were used to tie the steel together during erection and to aid in lining up the columns, Figs. 11 and 12.

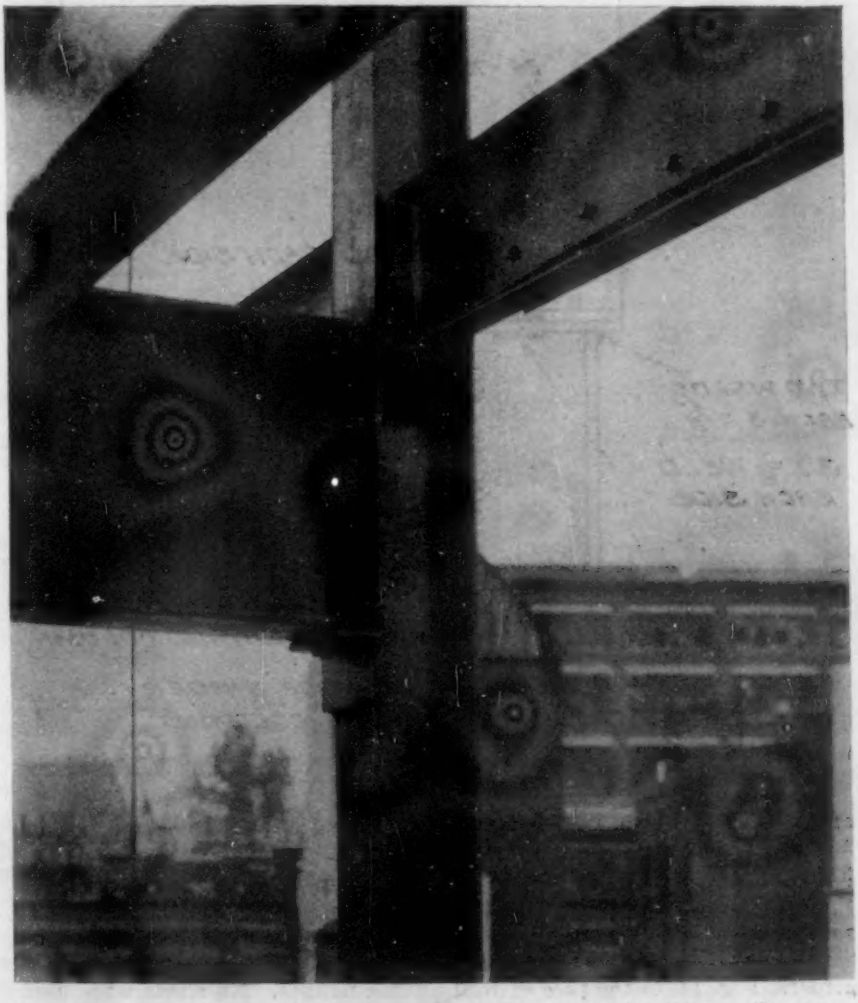


FIG. 12. TYPICAL CONNECTION GIRDER TO WALL COLUMN IN ARC WELDED FRAME OF BUILDING 36, PITTSFIELD WORKS

The writer sees no objection to the use of erection bolts in welded buildings; indeed, to attempt to erect a beam and column building without them seems very uneconomical. Furthermore, if the necessary strength is secured there is no valid reason against using bolts in connections of ordinary interior beams, bracing and secondary framing, provided, of course, they can be used more cheaply than welding.

As in the Bridgeport building described above and in the West Philadelphia welded trusses of the General Electric Co., a unit working stress

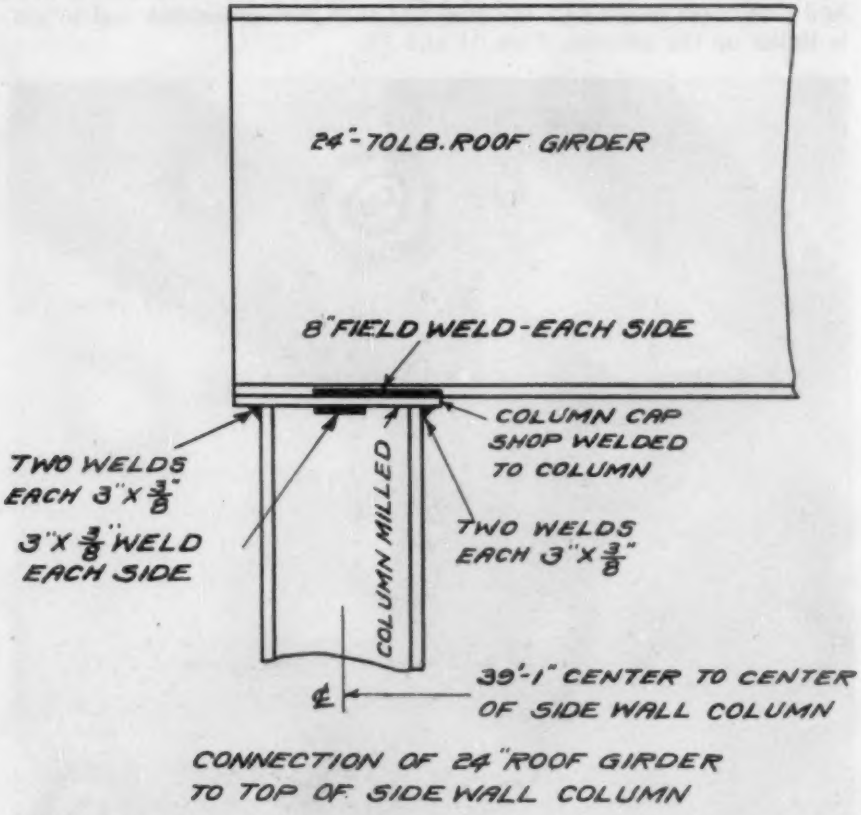

24"-70LB. ROOF GIRDER
8" FIELD WELD-EACH SIDE
COLUMN CAP SHOP WELDED TO COLUMN
TWO WELDS EACH 3"X 3/8"
3"X 3/8" WELD EACH SIDE
COLUMN MILLED
TWO WELDS EACH 3"X 3/8"
39'-1" CENTER TO CENTER OF SIDE WALL COLUMN
CONNECTION OF 24" ROOF GIRDER TO TOP OF SIDE WALL COLUMN

FIG. 13. CONNECTION OF 24 IN. ROOF GIRDER TO TOP OF SIDE WALL COLUMN, GENERAL ELECTRIC COMPANY'S ARC WELDED BUILDING 36, PITTSFIELD, MASS.

of 11,300 lbs. per sq. in. of minimum shearing section was used, giving 3000 lbs. per linear inch for longitudinal shear for $\frac{3}{8}$ in. triangular fillets with corresponding smaller values for smaller fillets.

The principal use of field welding lay in the connections of 24 in 70 lb. roof girders, Fig. 13, to the top surfaces of wall column caps and in the connection of top and bottom flanges and webs of 27 in. 91 lb. main floor girders, Fig. 11, to the face of wall column flanges. No rivets were used but bolts were employed for field connections of secondary members.

Steel for both the Pittsfield and Bridgeport buildings was welded at the American Bridge Co.'s welding shop at Trenton, J. H. Edwards, chief engineer; and William Dalton and the writer represented the General Electric Co.

Advantages of Welding

1. Welding is noiseless while riveting is extremely noisy. This is important in densely populated areas, or in the neighborhood of hospitals, hotels or apartment houses. Welding does not eliminate all noises during

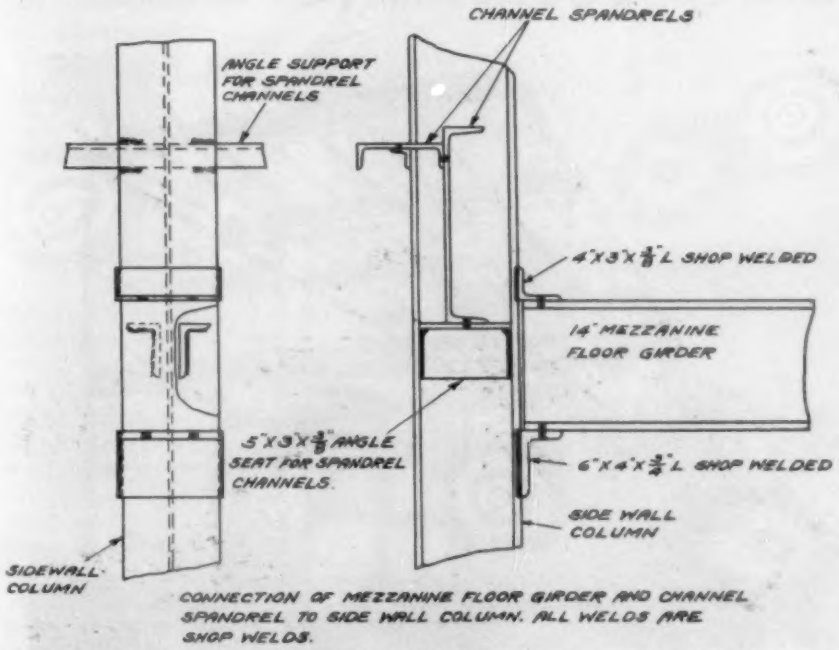

CHANNEL SPANDRELS
ANGLE SUPPORT FOR SPANDREL CHANNELS
4"X3"X⅜" L SHOP WELDED
14" MEZZANINE FLOOR GIRDER
5"X3"X⅜" ANGLE SEAT FOR SPANDREL CHANNELS
6"X4"X¾" L SHOP WELDED
SIDE WALL COLUMN
SIDEWALL COLUMN
CONNECTION OF MEZZANINE FLOOR GIRDER AND CHANNEL SPANDREL TO SIDE WALL COLUMN. ALL WELDS ARE SHOP WELDS.

FIG. 14. CONNECTION OF MEZZANINE FLOOR GIRDER AND CHANNEL SPANDREL TO SIDE WALL COLUMN. ALL WELDS ARE SHOP WELDS. BUILDING 36, PITTSFIELD, MASS.

building construction, but the noise of riveting is avoided. There still remains the steam shovel, the gasoline engine and steam hoist.

2. The strength of tension members in riveted trusses is reduced by rivet holes. With welded joints these holes are not used and all the steel is effective, hence greater strength. For example, in typical tension members recently designed 100 per cent of the cross sectional area of welded members was effective as contrasted with 83 per cent for riveted tension members.

3. For a given amount of steel, greater strength can be secured by welding than by riveting. As evidence of this, I point to tests of Lloyd's Register of Shipping, where welded joints show strengths of from 92 per cent to 100 per cent of the strengths of the connected parts. Riveted joints cannot reach such efficiencies.

4. In some structures, particularly those having trusses, welding is cheaper than riveting.

5. Welding often eliminates many unnecessary steel parts and reduces the cost of construction. In the recently completed West Philadelphia welded trusses in the building of the General Electric Co. over a thousand gusset plates in the roof trusses alone eliminated by adopting the welded design. In riveted work these plates would have been necessary.

6. In plate girders a considerable saving in weight of steel amounting to as much as 25 per cent, may be effected by welding. This is due to economies in elimination of loose fillers; a greater "web equivalent;" no

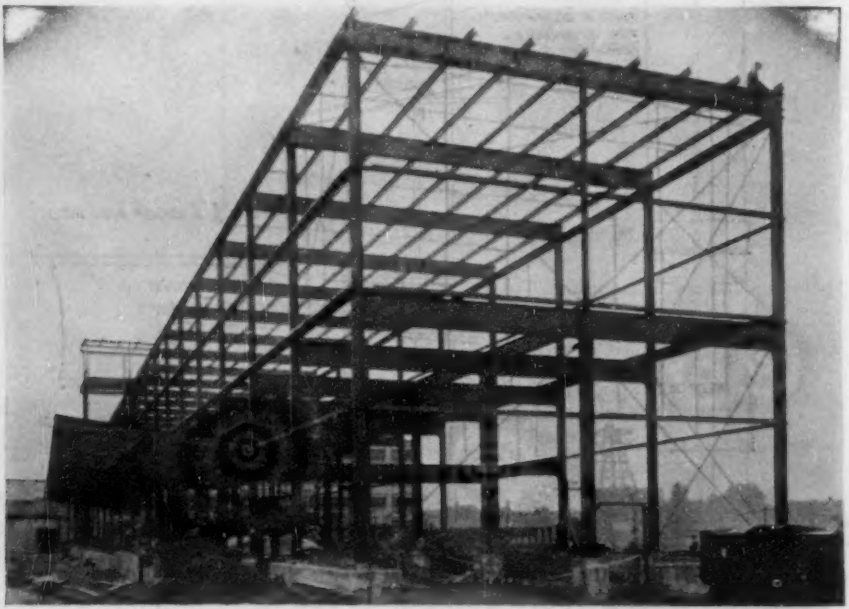


FIG. 15. COMPLETED FRAME BUILDING 36, PITTSFIELD WORKS, LOOKING SOUTH

loss in tension flanges due to rivet holes; and to use of flat bars instead of angles as stiffeners.

Current Welded Construction

The principal welded buildings now under construction include a six-story power house at Atlantic City, an eleven-story hotel at Virginia Hot Springs, a four-story office building in Cleveland, Ohio, and a one-story shop at South Portland, Me. And the past year has witnessed the completion of welded buildings at the following places: West Philadelphia, Pa.; Bridgeport, Conn.; Pittsfield, Mass.; Melrose Park, Ill.; Emeryville, Cal.; and of welded bridges at Pittsburgh, Pa., and Chicopee Falls, Mass. In addition to these structures, many large tanks and pipe lines are being built or have been completed recently.

The extent to which welding has been adopted in steel construction is best shown by a recent, more or less complete tabulation of welded structures which the writer has just made and published, and in which welding was wholly or partially used. This list includes eight bridges, forty-three buildings, twenty-eight ships and pontoons, eleven large tanks and several miscellaneous structures. While the list of buildings was fairly complete, no attempt was made to include any welded tanks except some larger ones as illustrations of this class of work, and no welded pipe lines were included in the list because of the very great number now in use.

Strengthening Steel Structures

One of the most interesting adaptations of welding lies in strengthening existing bridges and buildings. In performing this by riveting it is generally necessary either to knock out old rivets or to drill holes in the existing steel. Both of these processes are very costly. When welding is used, however, neither of these operations are generally necessary, and the additional steel is merely clamped or tack welded in place preparatory to final welding. Consider, for example, the ordinary box section of an end post in a truss bridge consisting of a wide cover plate, four angles and two webs. To add an additional cover plate or two additional webs requires drilling holes in the old cover or webs, whereas with welding no holes need be drilled. All that is necessary is to clamp or tack weld in order to hold the new plates while being permanently welded. Of course, the widths of new plates must be chosen to clear existing rivets. Similarly it is often a very easy process to strengthen stringers and floor beams by adding plates or other shapes without disturbing existing steel or existing traffic. Recently I saw a bridge floor being strengthened by riveting a cover plate to each of the top and bottom flanges of several score of I beams spaced about 3 ft. on centers and transversely to the axis of the bridge. Each flange throughout its length was drilled for the new rivets. I think I am stating it conservatively when I say that the cost of adding these plates by welding would have been not over one-fourth of the cost as performed.

An attractive application of welding lies in joining new steel to an existing steel framed building. For example, consider the connection of a I beam in a floor of a new building to the face of the flange of an H column in an old building, the column surrounded by concrete. To rivet this requires a removal of concrete not only in front of the column but on the sides and rear of the flange as well, in order that holes may be drilled in the flange and in order that sufficient space be secured behind the flange to "buck up" the rivets. In welding, however, one need remove only the concrete from the face of the column to weld a seat upon which the I beam may be set; then the necessary welding is performed.

Some Structural Aspects of Welds in Specimens of Fire-Box Steel Tested at Normal and Elevated Temperatures*

Tests of
the
San Francisco Section of the
American Welding Society

By H. W. TAYLOR, K. V. LAIRD, H. E. MORSE, VERNE LANGFORD, T. D. RADCLIFFE†

Introductory

SINCE the work presented in this report has been preceded by a report published last September in the Journal of the American Welding Society, the relation of the present report to the earlier one will be briefly sketched.

The present work covers a structural examination of a portion of the specimens of the previous report which covered physical tests upon specimens made from fire-box steel and welded with a variety of welding rods.

The present presentation of micro and macro structure examination is the work of Mr. H. W. Taylor of the H. E. Morse Laboratory and the preparation of the report was collaborated in by H. E. Morse, Verne Langford, T. D. Radcliffe and K. V. Laird and presented by the latter at a joint meeting of the Golden Gate Chapter of the American Society for Steel Treating and the San Francisco section of the American Welding Society, held in Oakland, Cal., May 9, 1928.

A more complete study of the variation of physical properties of welds from certain of the welding rods over a range of temperature is now in process and will be reported later on with a further microscopic examination when these physical tests have been completed.

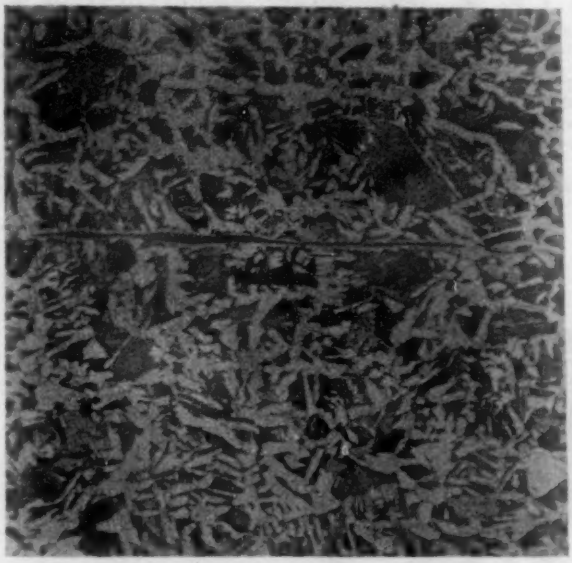
Grateful acknowledgment is made for the financial assistance afforded by the American Bureau of Welding which generously supplied funds which made the work covered by this report possible as well as the contemplated structural studies to come later on.

The steel plate used in this investigation was tested as to physical properties and these are reported in the September, 1927, issue of the Journal of the American Welding Society. It was purchased from a reputable source and as no radical unconformities showed in these physical tests this plate of fire-box steel was assumed to be representative

*To be presented at Fall Meeting, A. W. S., October, 1928. Investigation sponsored by Fundamental Research Committee of American Bureau of Welding.
†Members sub-committee.

of fire-box as supplied to the market. In the light of the later miscoscopic examination it is doubted whether it would meet the more rigid requirements of modern hazardous service.

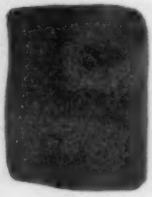
The fire-box steel used for these tests showed marked segregations with extreme variation in grain size. The large grains are found in bands and slag inclusions, surrounded by narrow ferrite areas and are numerous. Fig. 19 is indicative of this condition.



×100

FIG. 19. FIRE BOX STEEL PARENT METAL

MACRO NO. 19



Macro No. 19 is the metallographic section from which Fig. 19 is obtainable.

Welded Material Selected

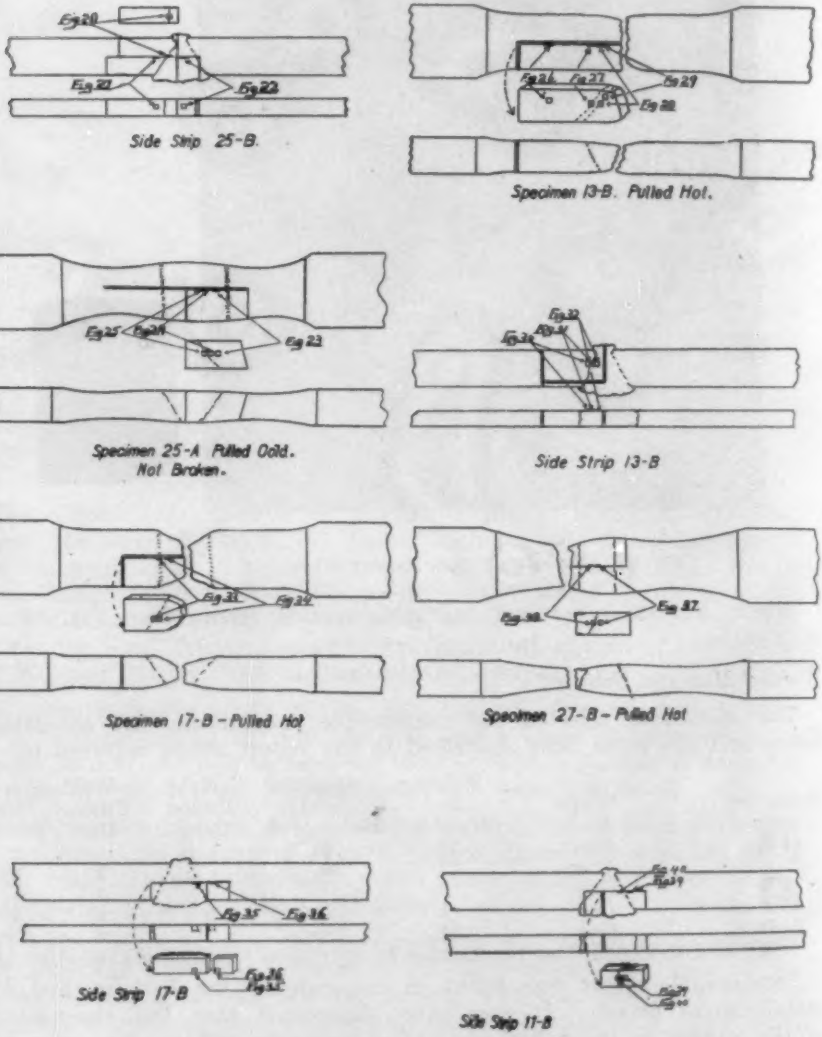
The specimens selected for microscopic examination are tabulated below and are more fully described in the report above referred to.

Specimen Number	Type Weld	Welding Rod Number	Annealed and Hammered	Weld Pulled Cold	Weld Pulled Hot	Side Strip
11 B	Elect.	18	No			x
13 B	Elect.	21	No		x	x
17 B	Gas	3	Yes		x	x
25 A and B	Gas	1	No	x	x	x
27 B	Gas	24	Yes		x	

"x" indicates conditions represented by specimens obtained microscopically.

Considerable effort was spent in determining the best method of metallurgical attack. It was early discovered that the appearance of the section to the naked eye (after polishing and etching) was no indication of the microstructure. Some well defined differences that

were plain to the naked eye lost all or nearly all their identity when viewed under the miscoscope. Fig. 20 is a section of specimen number 25 B side strip and is at a point where a distinct transition zone is visible to the naked eye. This magnification of 15 diameters the light was thrown off center and the transition is found to be a sharp termination of gas or pit holes. The detail of the structure is ferrite and pearlite grains and are apparently the same on one side of the line of demarkation as on the other. This is more marked under the microscope than is shown in F.g. 20. Under higher magnification (as will be


Side Strip 25-B.
Specimen 13-B. Pulled Hot.
Specimen 25-A Pulled Cold. Not Broken.
Side Strip 13-B
Specimen 17-B - Pulled Hot
Specimen 27-B - Pulled Hot
Side Strip 17-B
Side Strip 11-B

PHOTOMICROGRAPH DIAGRAM SHOWING LOCATION OF AREAS PHOTOGRAPHED IN EACH SPECIMEN

Side Strip 25B

FIG. 21. PARENT ×100

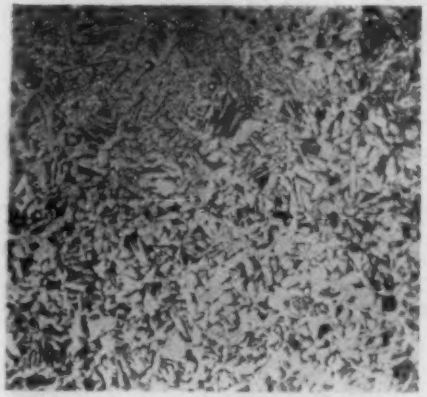


FIG. 20. ×15

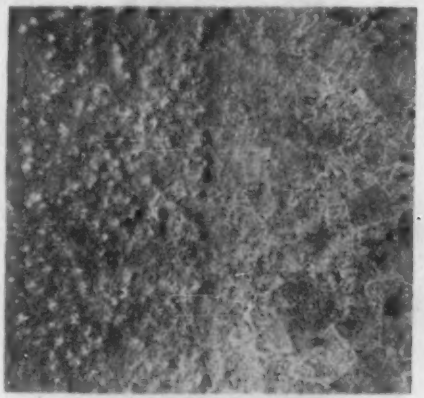
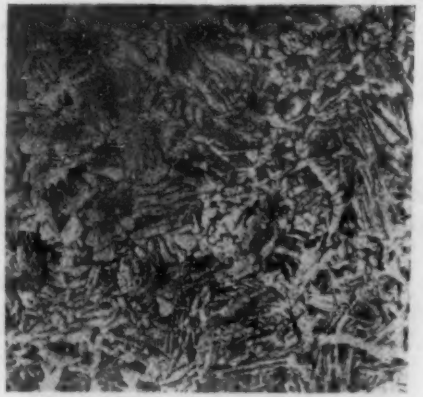


FIG. 22. WELD ×100



MACRO NO. 20

These illustrations were taken about ⅝ in. apart. Examination of three different surfaces of this weld failed to reveal any abrupt structural change. When specimens are viewed with the naked eye a transition zone about ⅝ in. wide was apparent. Note these photos have been reduced to about ⅔ their original size.

SPECIMEN 25 B HOT—Under the microscope even at low power there is no defined transition zone. The only apparent difference is a gradual enlargement of grains from parent metal to weld metal. The weld metal is extremely coarse grained.

The specimen when viewed by naked eye shows a narrow transition band. This is lost when enlarged only a few diameters.

Test Specimen—25-A—Pulled Cold

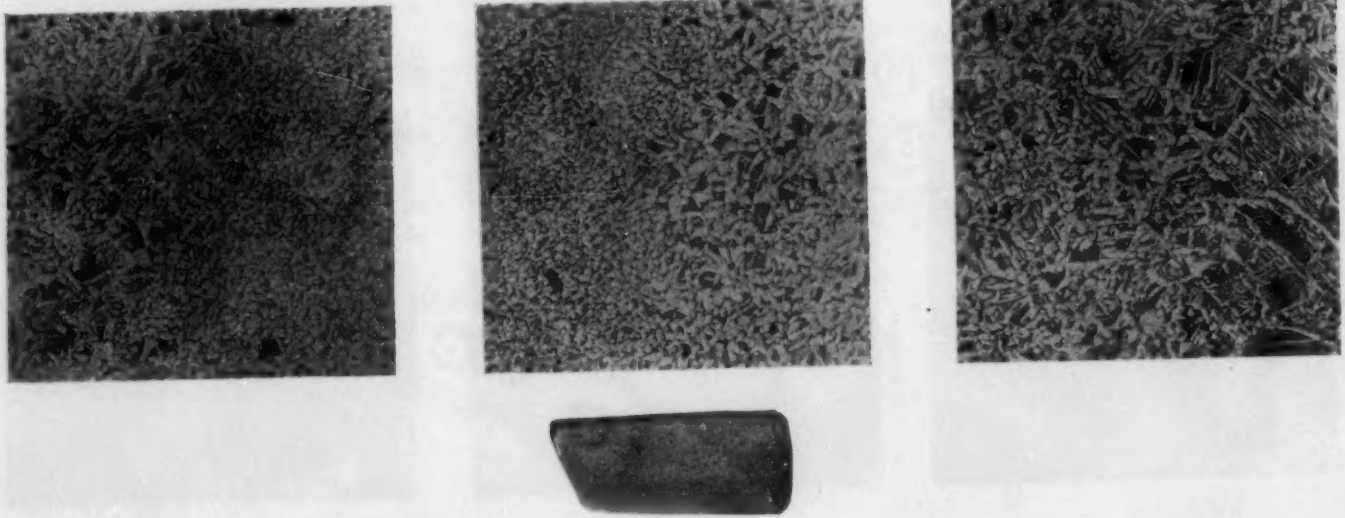
FIG. 23. PARENT METAL. ×100

FIG. 24. ×100

FIG. 25. WELD METAL. ×100

TEMPERATURE GRADATION DOWNWARD TOWARD THE LEFT

Unannealed ⟵⟶ Annealed at Critical ⟵⟶ Annealed Above Critical (Overheating) ⟵⟶ Cast Structure



MACRO NO. 24

The gradation from parent metal to transition and from weld metal to transition is gradual. There is a fairly sharp change of grain size in center of transition. These photographs have been reduced to about ⅔ original size.

shown later) the section shows no marked structural change from one end to the other.

It was concluded, therefore, that the comparison should be made at a magnification of 100 diameters, since lower magnification did not give a true indication of the structure of the metal.

The several metallographic specimens were photographed with a magnification of 2 diameters as this appeared to give an illustration comparable to naked eye observation and at the same time somewhat enhance the detail. These are designated by macro series numbers to conform the figure number of the photomicrograph.

While it is realized that the differences in continuity observed by the naked eye may have some bearing on the properties of the welds, they have not been considered where they have not been substantiated by corresponding difference of microstructure. A study of such differences might be a basis for work at some future time.

Sketches of the several test bars have been made to show the positions of the micro-sections taken and the positions of the photographs made from the sections.

Specimen number 25 was chosen for microscopic examination because it showed physical properties of the weld metal which were equal to or better than the parent metal. Figs. 21 and 22 show the microstructure of the metal of the side strip which has not been subjected to stress. The two illustrations were taken about three-eighths of an inch apart, one being in the weld and the other in the parent metal. There was a marked structural change but the parent metal gradually merged into that of the weld metal. Examination of three different sections from this side strip failed to show any abrupt change. While the grain size of the weld metal is large it merges easily into the transition and finally to the parent metal. When viewed with the naked eye, (Macro No. 20), a transition zone about three-eighths of an inch wide was observed. Fig. 20 (photomicrograph) already mentioned was taken from this section.

Figs. 23, 24 and 25 show the structure of this same weld after being pulled cold. The gradation from parent metal to transition and from weld metal to transition is gradual with a fairly sharp change of grain size at about the middle of the transition metal.

The photographs were taken close together though not directly abutting each other. This specimen was characterized by the fact that practically all the elongation took place outside of the weld. The photographs show the presence of considerable carbon both in the weld metal and transition zone. The ultimate strength of this specimen was greater than that of the parent metal. Macro No. 24 is metallographic specimen from which Figs. 23, 24 and 25 were taken.

The specimen of this weld that was pulled at 900 deg. F. (Number 25 B) was examined. Even at low power there was found no definite transition zone. The only apparent difference is a gradual enlargement of the grains from the parent to the weld metal. The microstructure is practically a duplicate of Figs. 21 and 22.

FIG. 26. PARENT METAL. ×100

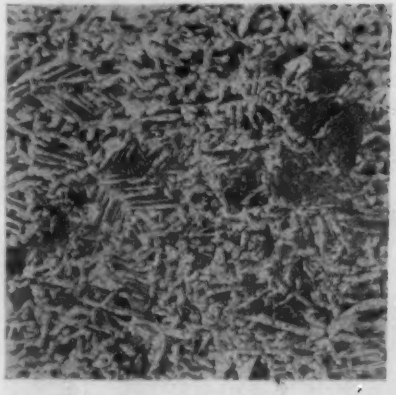


FIG. 27. ×100

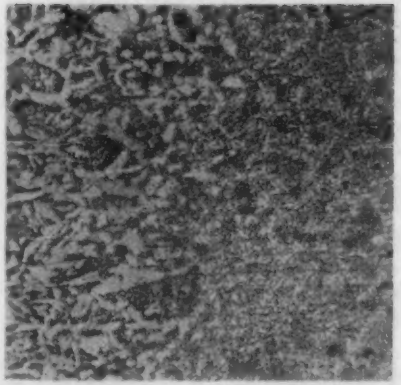
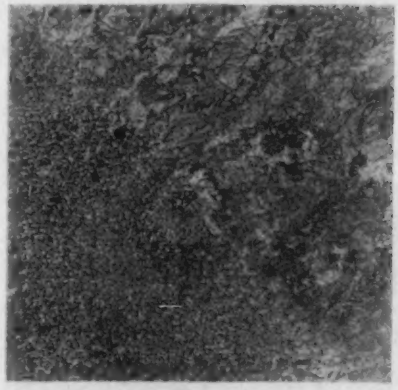


FIG. 28. WELD METAL. ×100



TEST SPECIMEN 13-B. NOTE: THESE PHOTOGRAPHS HAVE BEEN REDUCED TO ABOUT ⅔ THEIR ORIGINAL SIZE

The side strip, which was not heated, and 13-B, pulled hot, are practically identical. Parent Metal grades easily to very fine grained transition and finally across a sharp line of demarkation to weld metal.

Some areas showing high carbon at bottom of weld. A spot on side strip near or in button shows very large grains.

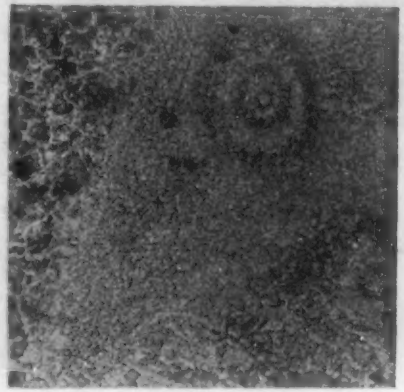


FIG. 29. ×100

MACRO NO. 27

Side Strip 13B

FIG. 30. PARENT METAL ×100

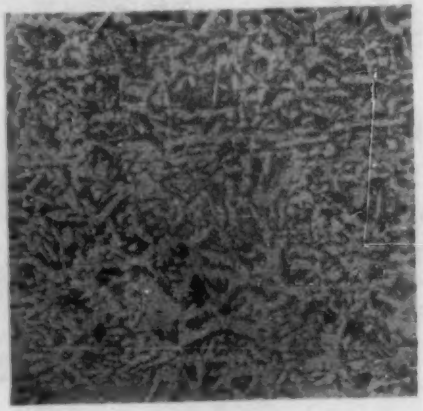


FIG. 31. ×100

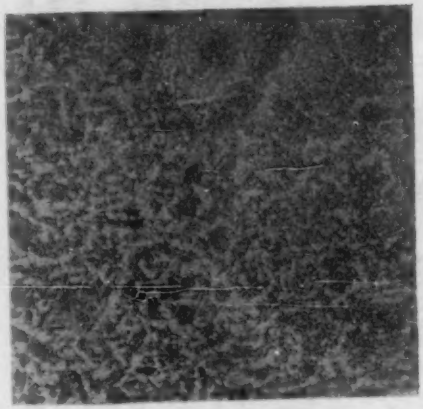
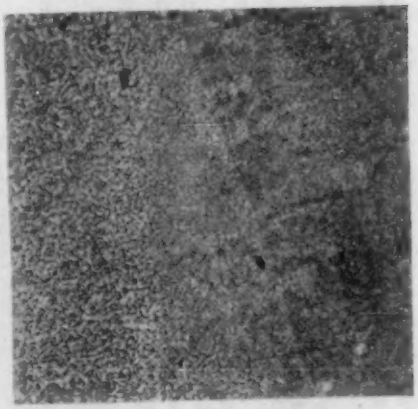


FIG. 32. WELD METAL ×100



MACRO NO. 31

Note: These photographs have been reduced to about ⅔ their original size.

Specimen number 13 was chosen as it represents a high carbon electrode rod which was fair on cold pull and rather low on high temperature pull. Figs. 26, 27 and 28 show the structure of the weld after pulling at 900 deg. F. The interesting point shown here is the very fine grain of the transition metal and a distinct change of structure at the boundary line of the weld metal. The weld metal is almost carbon free. Only a few scattered areas of pearlite were discernable at a magnification of 1500 diameters. The weld was somewhat dirty and there were areas near the bottom of the "V" that contained considerable carbon. Fig. 29 shows one such area merging into the rest of the weld metal.

The side strip of this specimen is practically identical with the hot pulled specimen in microstructure with the exception that the weld metal varies from very fine grains at the top to large grains near the bottom of the "V". Figs. 30, 31 and 32 show this specimen near the top of the weld showing fine grained weld metal.

Macro No. 27 and No. 31 show the metallographic specimens from which these six figures were obtained. The transition zones are very evident and correspond to the sections shown in the several photomicrographs.

It will be noted that Macro No. 31 shows many cavities in the weld metal which are not observable in Macro No. 27, which was taken from the side strip. This seems to indicate variations in the welding operation.

Specimen number 17 was chosen as an average low carbon gas rod. Figs. 33 and 34 show the structure found. The general structure resembles that of specimen number 25 although the grain size is more uniform. Where number 25 shows a fairly fine transition zone and rather coarse weld metal, number 17 shows very little difference in grain size across the entire section. The parent metal merges into the transition zone almost imperceptibly and the line between the transition and the weld metal is rather indistinct. The ferrite grains of the weld metal are smaller while the pearlite grains are practically as large as those of the parent metal.

The structure of the side strip from specimen number 17 is radically different from that of the hot pulled specimen. The weld is very dirty with strings of gas holes running in characteristic crescent shapes. Fig. 35 shows a portion of the surface at low magnification. This is unetched and illuminated from the side. The structure of the weld metal, Fig. 36, is extremely fine grained. This is directly opposite to the weld metal of the hot pulled specimen. The carbon content appears to be somewhat lower.

This further emphasizes the variation from point to point in any one weld which is especially apparent in Macro No. 35. Macro No. 34 is the metallographic specimen from which Figs. 33 and 34 were obtained.

Specimen number 27 was made with a special gas rod and the physical properties were somewhat lower than those of specimen number 25. It was pulled at about 950 deg. F. Figs. 37 and 38 show the structures obtained. The outstanding features of this weld is the entire absence of a transition band either under the microscope or when viewed with

Test Specimens 17B—Pulled Hot

NOTE: These photographs have been reduced to about ⅔ their original size.

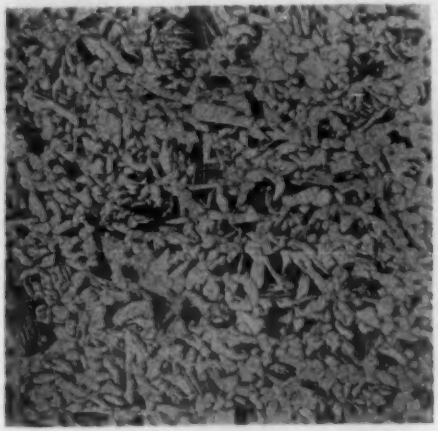
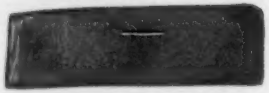


FIG. 33. PARENT METAL. ×100



MACRO NO. 34

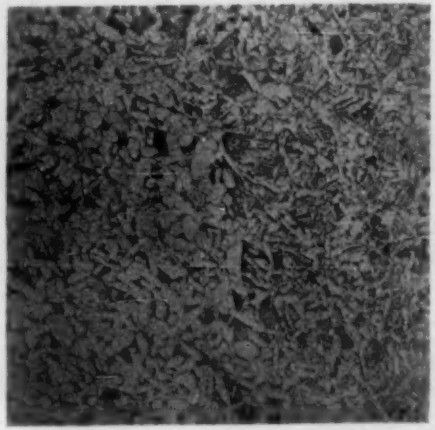


FIG. 34. WELD METAL. ×100

Side Strip, 17B

These photographs have been reduced to about ⅔ their original size.

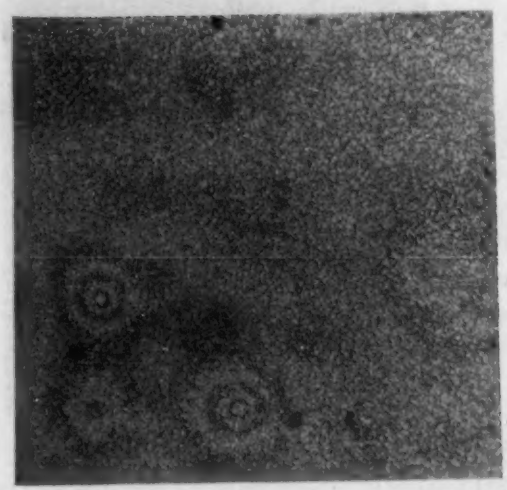
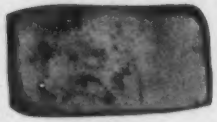


FIG. 36. WELD. ×100



MACRO NO. 35

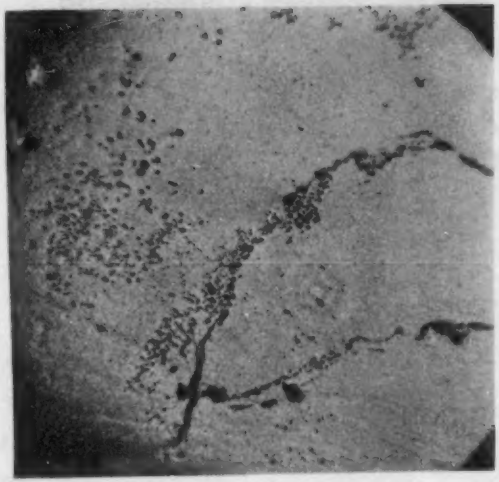


FIG. 35. ×25

Side Strip—No. 11B

NOTE: These photographs have been reduced to ⅔ their original size.

MACRO No. 39

EVEN GRADATION

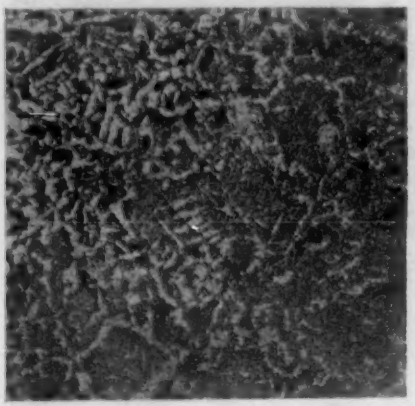


FIG. 39. PARENT METAL. ×100.

FROM

TO

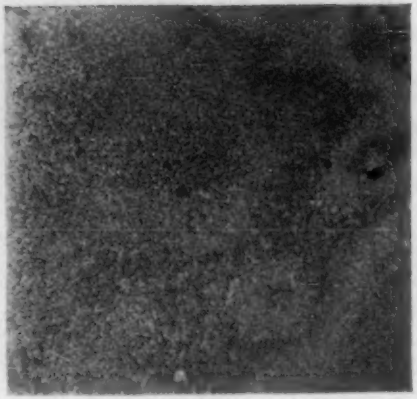


FIG. 40. WELD METAL. ×100

Test Specimen—27B—Pulled Hot

NOTE: These photographs have been reduced to about ⅔ their original size.

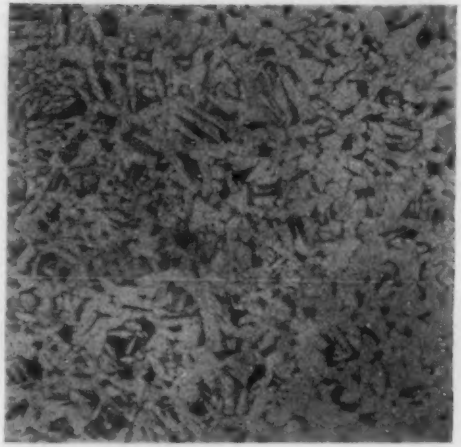


FIG. 37. PARENT METAL. ×100

MACRO NO. 37.

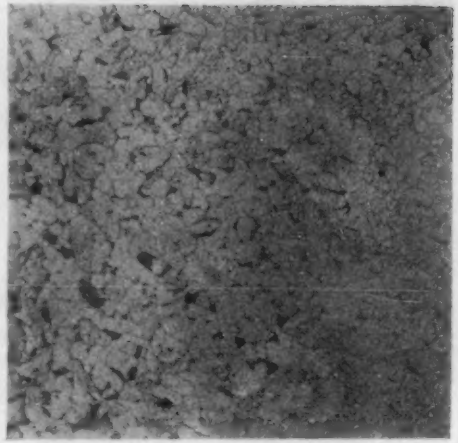


FIG. 38. WELD METAL. ×100

The transition from parent metal to weld metal is very gradual. No abrupt change is evident. The entire transition zone is narrow.

the naked eye. The structure graduates quickly but evenly from the parent metal to the weld metal and the latter is almost carbon free. The weld metal appears extremely ductile with low strength, but due to nickel content was strong and the specimen broke outside the weld. Macro No. 37 shows the metallographic specimen from which Figs. 37 and 38 were obtained and there is no apparent transition zone visible.

Specimen number 11 represents a special electrode rod. Tensile properties of welds made with this rod are high together with good elongation and reduction of area. Figs. 39 and 40 illustrate the structure of the side strip of this material. The outstanding point observed was the extremely fine grain transition and weld metal. While marked, the transition is not abrupt and both parent and weld metal merge gradually.

Macro No. 39 shows the metallographic specimen from which Figs. 39 and 40 were obtained. The transition zone is distinctly visible to the naked eye.

A thorough study of the weld metal of all specimens was made at 1500 diameters magnification. Wherever carbon is present it exists as pearlite more or less definitely laminated.

Conclusions.

It is easy to distinguish between electric and gas welds. The electric weld metal is usually characterized by a grain alignment extending in the direction in which the metal is being deposited. The gas weld metal, on the other hand, shows no similar grain alignment.

In general the electric weld shows under the microscope a fairly well defined line of demarkation between the weld metal and transition which is not true of the gas welds.

It has been shown in the previous report that the tensile tests of electric welds fractured along a sharp line apparently at the edge of the weld metal. While not definitely proven in this report it seems to be a logical conclusion that the break actually occurs at the sharp line of demarkation generally observed between the metal and the transition.

It is of interest to note that specimen number 17, Fig. 35, which gave poor physical results also showed a very dirty weld under the microscope and that specimen number 25, which gave exceptional properties showed no evidence of extreme variations in grain size or structure. The parent metal merged into the weld metal without any abrupt change. Specimen number 27 lends further support to the deduction that the lack of any radical change in structure or line of demarkation goes hand in hand with good strength in a weld. The fact that one of these was hammered and annealed and the other unannealed is interesting to note.

The alignment and line of demarkation referred to are best illustrated in Fig. 28 and also in Fig. 32.

The unexplained variations observed in the physical appearance of the weld leads to the belief that more concordant results might be obtained by the use of automatic welding machines thus eliminating the personal factor.

It is known that grain growth can occur at relatively low temperature

when the specimen is under high strain. It is well to note that no definite evidence of grain growth was found in any of the specimens examined.

The difference observed in microscopic examinations have only in a few cases been confirmed by microscopic analysis. It is felt that such differences as appear in a microscopic section, however, should not be ignored and may prove an indication of certain weld conditions not otherwise evident.

The correlation of the macro sections with the results of physical tests has not been attempted as it appears more difficult than the correlation of the microstructure.

The structural difference between the hot and cold pulled specimens appeared to be merely the result of irregularities in the welding.

Elevated Temperature Tests of Welds*

Conducted Jointly by San Francisco Section AMERICAN WELDING SOCIETY and Materials Testing Laboratory STANFORD UNIVERSITY

Second Section of Physical Tests— First Section Published September, 1927

Journal of the AMERICAN WELDING SOCIETY

The current investigation of welds at elevated temperatures is made possible through the co-operation of the American Bureau of Welding, the San Francisco Section of the American Welding Society, and Stanford University. Valuable assistance has been rendered by individuals and firms to whom personal acknowledgment has already been made.

THE present work, the first part of which was reported in the September, 1927 issue of the Proceedings,† has been undertaken in the full realization of the limited scope being attempted. The desire to render information concerning the behavior of welds at elevated temperatures more generally available has prompted the undertaking.

No claim is made that this paper gives a final answer regarding the practical properties of welds. It is presented with the hope that it may stimulate a more general interest in the subject of welding and provoke fuller and more exacting investigations.

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*To be presented at Fall Meeting, A.W.S., October, 1928. Investigation sponsored by Fundamental Research Committee of the American Bureau of Welding.

†Elevated Temperature Tests of Welds, Journal of the American Welding Society, Vol. 6, No. 9, September, 1927, p. 30.

The results of our investigation will be given and then followed by suggestions which have arisen in the course of the work. In going into the details of the tests it will simplify matters to review briefly, in its relationship to the present report, the paper already cited.

A method of taking temperature, at the weld, without drilling the specimen was developed and tested. Fig. 1. This has been improved through a change of operation of the heating furnace and can, no doubt be further refined.

The first set of tests included two sets of specimens. One set of the original plate metal which was tested throughout the temperature range

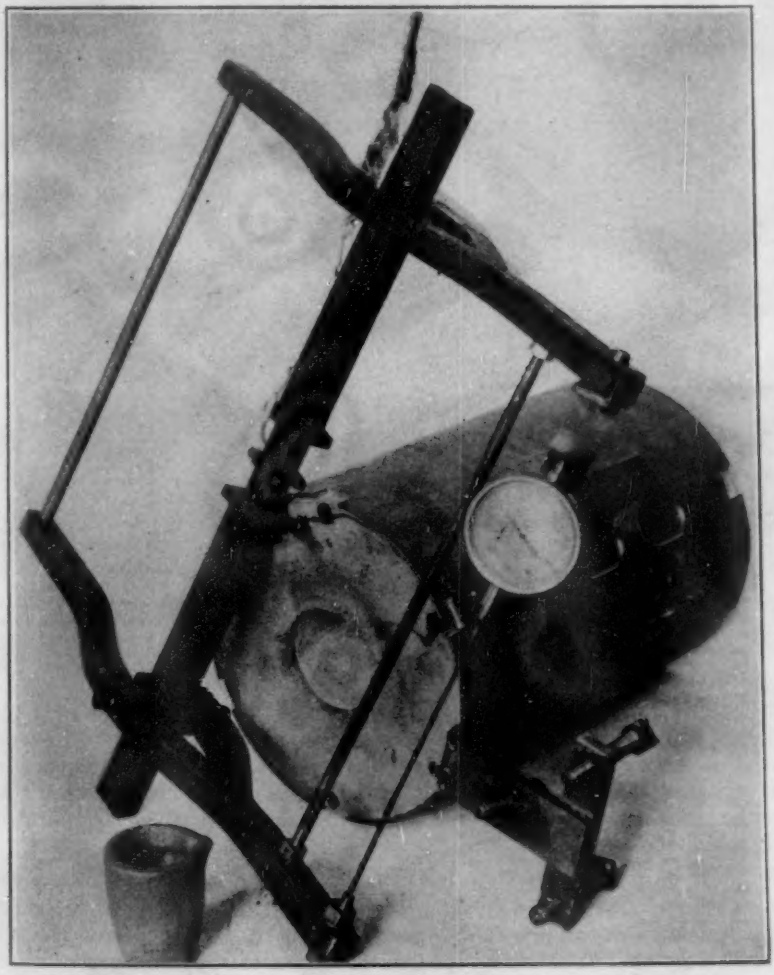

FIG. 1. EXTENSOMETER RIG AND FURNACE.—WITH SPECIMEN IN EXTENSOMETER. NOTE THE POSITION OF THE TEMPERATURE MEASURING CLAMP AT THE CENTER OF THE SPECIMEN WITH THERMOCOUPLE ATTACHED. THE WELD LIES DIRECTLY BETWEEN THE HALVES OF THIS CLAMP WHICH IS FIRMLY IN CONTACT WITH THE SURFACE OF THE SPECIMEN

to furnish a basis for comparison. The other set to make a survey of twenty-three welding rods submitted.

These were classified into gas or electric groups and also special and specification. All the special rods were included in the test. The ordinary specification rods were then classified according to carbon content and representative rods chosen in proportion to the number in each class.

In order to hold the program within the limits of available time and funds this survey was made by testing two specimens of each rod chosen, once being at room temperature and the other between 900° and 975° F.

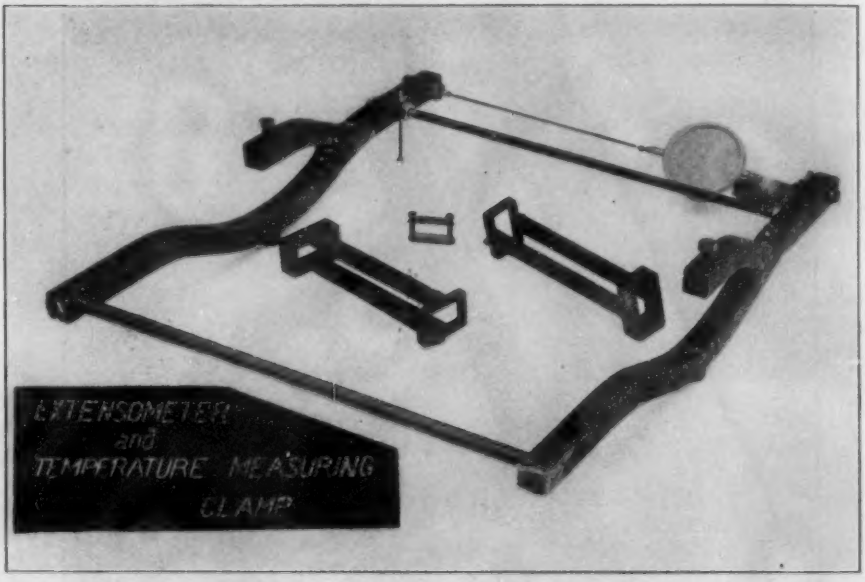

FIG. 2. THE CAGES OR HARNESS IN THE CENTER OF THE EXTENSOMETER ENTER THE FURNACE AND GRIP THE SPECIMEN AT POINTS TWO IN. APART. THE HOLES IN THE TEMPERATURE MEASURING CLAMP AT THE CENTER OF THE PICTURE ARE FOR INSERTION OF THERMOCOUPLE BY WHICH THE TEMPERATURE IS MEASURED

The results led to the conclusion that the self fluxing and nickel content rods warrant more detailed study. Also the welds which were strong at normal temperature were in general strong at the higher temperature. The ultimate strengths were consistent but the proportional limits appeared to require more than one determination at a given temperature to be conclusive.

While it was apparent that rods No. 1 and 24 presented an especial opportunity to make strong welds, it was felt that more general benefit would accrue from the knowledge gained by testing one rod from each of the classifications since each type has its practical applications.

The following welding rods were chosen for further test, the designations by number being the same as used in the report above referred to.

FIG. 3

SPECIMEN PLATE 53-54 BEFORE SLITTING. OPEN SIDE OF THE SINGLE "V" WELD SHOWING HAMMERING OF WELD METAL. ACETYLENE WELD

SPECIMEN PLATE 55-56 BEFORE SLITTING. NARROW SIDE OF SINGLE "V" WELDED PLATE SHOWING PENETRATION AND HAMMERING OF WELD. ACETYLENE WELD

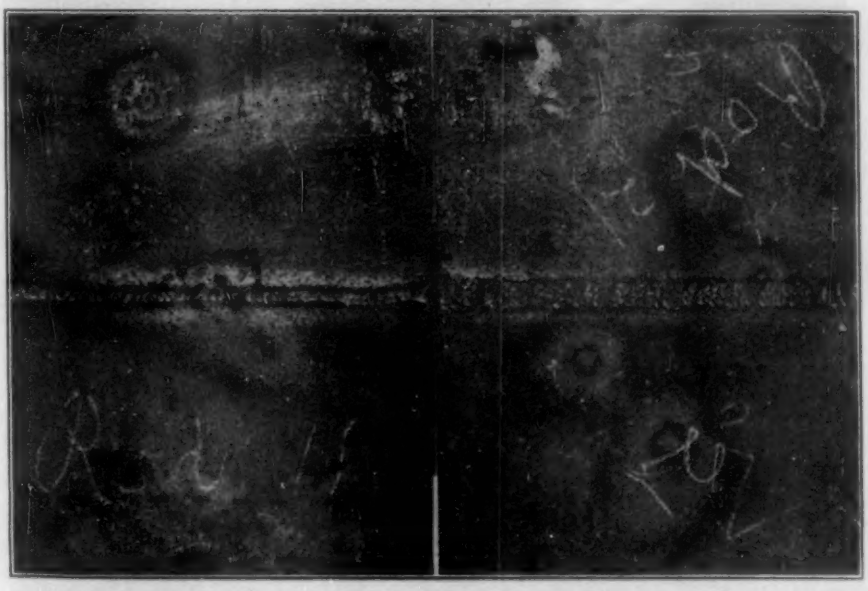

FIG. 4

SPECIMEN PLATE 57-58 BEFORE SLITTING. NARROW SIDE OR CLOSING BEAD-SINGLE "V" WELD. ELECTRIC WELD

SPECIMEN PLATE 59-60 BEFORE SLITTING. OPEN SIDE OF SINGLE "V" WELD. ELECTRIC WELD

Welding Rod No. 1.

(Specimen Plate 53-54 of the tests herein reported.)

A self-fluxing acetylene rod which showed unbreakable welds in machined section and ultimate strengths higher than the original plate both at room and elevated temperatures. Fig. 5.

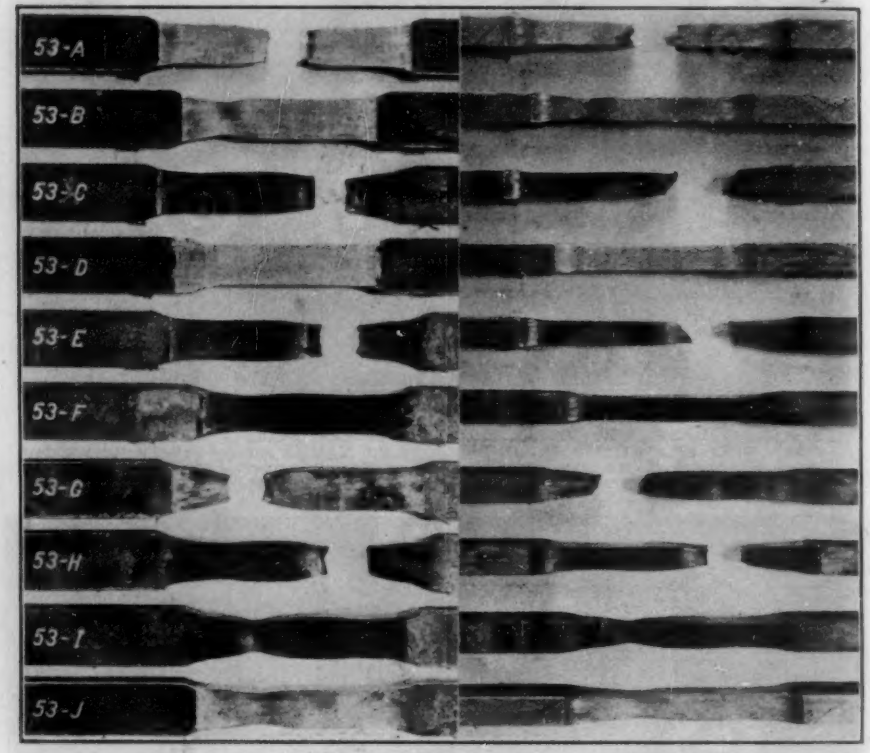

FIG. 5. SELF FLUXING—ACETYLENE WELDS—ANNEALED AND HAMMERED

Welding Rod No. 13.

(Specimen Plate 55-56 of the tests herein reported.)

A low carbon, specification (.055% C.) acetylene rod showing low strength but extreme ductility of weld metal. The specimen tested in the survey having a reduction of area of 79½% at 957° F. Fig. 6.

Welding Rod No. 11.

(Specimen Plate 57-58 of the tests herein reported.)

A low carbon electrode (.082% C.) falling between the two low carbon specifications of the Welding Society, Bulletin No. 2 for low carbon iron or steel. This rod was chosen as being representative of the low carbon group of electrodes, being of good quality in its class, but having no outstanding properties. Fig. 7.

Welding Rod No. 21.

(Specimen Plate 59-60 of the tests herein reported.)

A low carbon electrode (.144% C.) falling within specification E-1-B of the Welding Society which showed good strength for its type both cold and at elevated temperature. Fig 8.

The specimen plates are marked with two numbers which designate the halves of the plate before welding, the individual specimens after welding being identified by the first or odd number and a letter. The

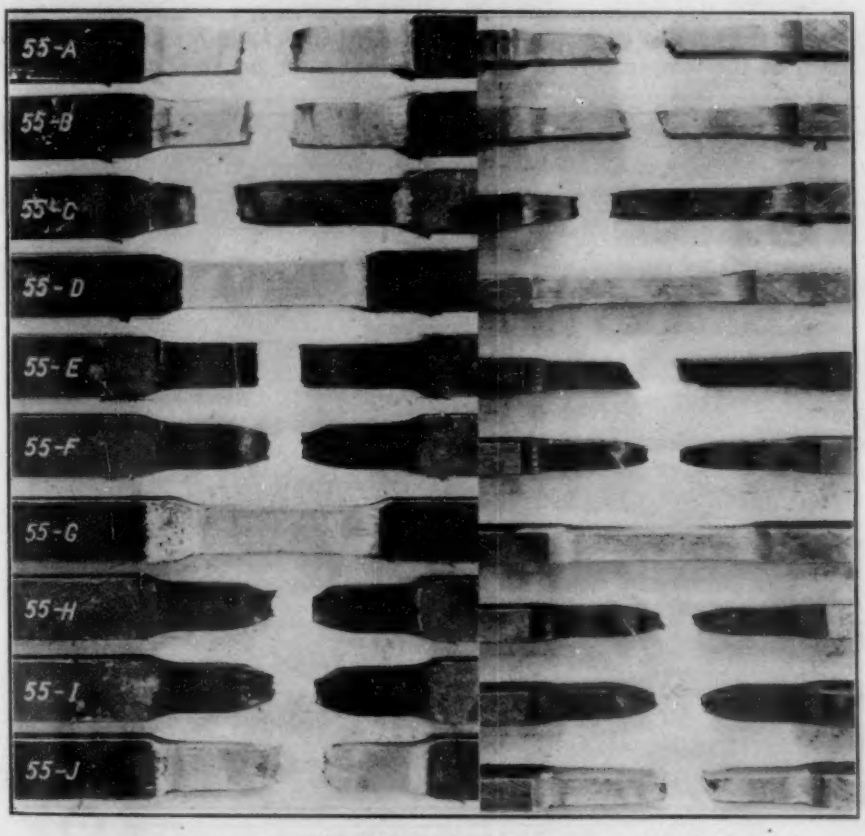

FIG. 6. LOW CARBON—ACETYLENE—ANNEALED AND HAMMERED

odd number was always placed at the top when testing. The position of the welded specimen in the plate is indicated by the letter following the plate number, as in Fig. 5, 6, 7 and 8.

Specimens were placed cold in the furnace the walls of which were well below the temperature at which the test was desired and the furnace and specimen together brought up to a stable temperature with a constant voltage on the element. By this means the temperature was held stable during the period in which the specimen was pulled.

The heat in the element of the furnace was concentrated in the end thirds which gave better gradients about the specimen than obtained in the preliminary survey. This method of operation was found to remove the necessity for making a correction for temperature difference between the temperature-measuring clamp and the specimen Fig. 1 and Fig. 2. This was due to the cooler furnace wall adjacent to the central portion of the specimen. Careful checking with standardized thermocouples in the specimen and in the temperature-measuring clamp showed that the two were at the same temperature throughout the range covered.

A recording potentiometer pyrometer was used to chart a complete thermal record of each specimen. An additional check upon the stabilization of the temperature of the specimen was the behavior of the exten-

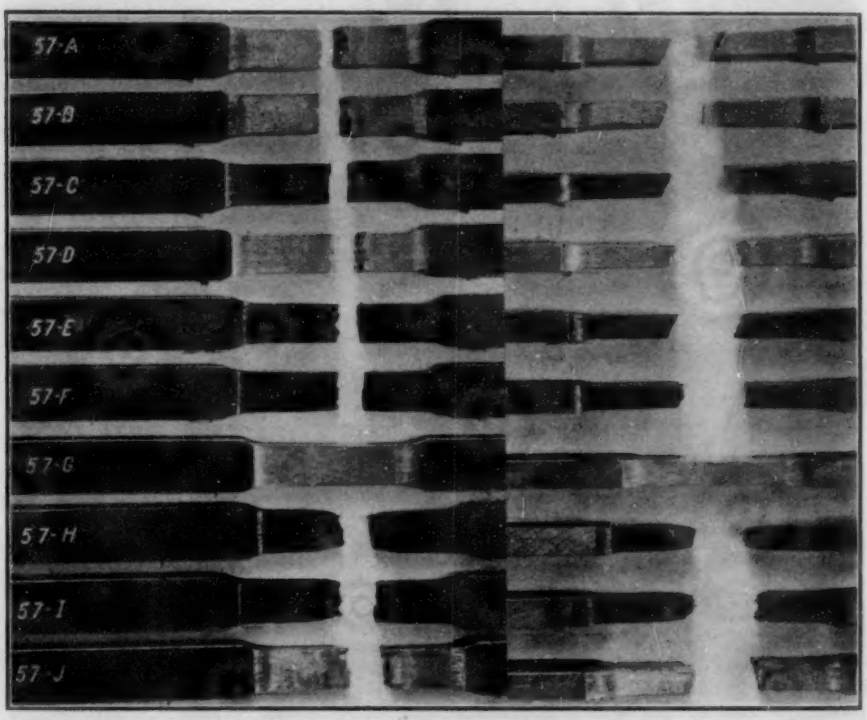

FIG. 7. LOW CARBON ELECTRODE

someter dial. This was graduated in ten thousands of an inch and inasmuch as the extensometer doubled the specimen extension, a movement of one twentieth of one thousandth of an inch could be observed without interpolation. This proved to be more sensitive to temperature variation than the pyrometer itself and more over covered the entire test length. It was used therefore, as the final criterion of stable temperature.

A specimen similar in dimensions to the test specimen and of the same material was used for the temperature studies, Fig. 1. The

conditions of the equilibrium hold only for bright surface contact between temperature-measuring clamp and specimen.

Along the lines of refinement of future technique it may be desirable to study the transient temperature changes in portions of the extensometer outside the furnace. The horizontal top bar where exposed to the warm air leaking up around the specimen at the top of the furnace may be subject to significant temperature changes due to atmospheric movement in the room about the testing machine. It may be advisable to make such parts of Invar and continue to use the same metal as the specimen for the harness inside the furnace to minimize differential expansion. The suggestion is prompted by the irregularities in the moduli indicated.

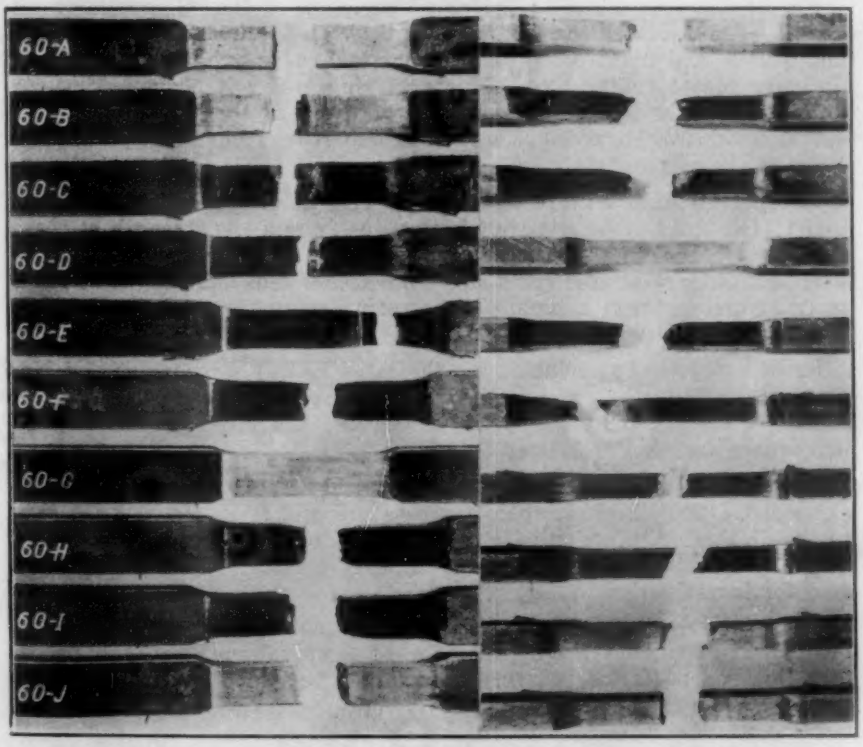

FIG. 8. LOW CARBON ELECTRODE—NOTE E SPECIMEN BROKE OUTSIDE WELD (60-G-TESTED AFTER PHOTO WAS TAKEN)

It is suggested that studies of the modulus of elasticity of welds and weld metal will greatly increase our knowledge of the process of weld failure. The proximity of two metals of radically different moduli undoubtedly sets up internal stresses under elastic deformation. An extreme case of this being a single "V" weld with non-ductile filling. This is unbalanced in that one side containing the greater amount of stiff metal will offer the greater resistance to deformation.

Lack of ductility of electric weld metal was apparent throughout the temperature range of these tests and to the extent which this characteristic is general it presents a problem for solution.

During the tests many small isolated fractures were noted throughout the electric welds. In the tests at room temperature where the specimens were visible as the test progressed these fractures were first noted at or near the proportional limit of the specimen and increased in number until the final break occurred.

The curves of Fig. 13 visualize the tensile properties of Table 1 the dotted curve showing the mean values of a duplicate set of specimens of original plate metal as shown in the preliminary report in the September, 1927, issue of the Journal type already cited. To the data of that paper one point has been added at 446° F. This is one of the "G" specimens of original metal located in the test plate between specimens tested at 750° and 870° F. and its value verifies the original curve published in the preliminary report referred to. This verifying test was prompted by the dip in the lower temperature portion of three of the welded specimen curves which was regarded as a striking departure from the experimental curve of the original plate.

Another striking feature is the rapid rise in strength with temperature of rod No. 13 to a relatively high value from a low strength at room temperature and without the dip shown by the other three. The consistent performance of this rod along with its low tensile strength at room temperature suggests a possible interesting comparison of metal structures with the other welds tested.

From a practical standpoint the indicated loss of strength of rod No. 11 at about 300° F. is of especial interest. Specimen 57D was tested to check the unexpectedly low point at 300° F. and broke at 300 pounds per square inch below 57B at 305° F.

The relative order of strength of the welds tested appears to be the same above 700° F. as at room temperature and is in marked contrast to the dissimilar behavior within the range from 200° to 600° F. This latter temperature zone, therefore, appears to offer the more fruitful field for investigation.

The relatively sustained values of proportional limit shown by welding rod No. 2 throughout the upper range of temperature Fig. 14 suggests that this rod possesses practical advantages beyond those already indicated by the tensile curves.

Experience has shown that certain alloy electrodes, among them nickel, when suitably fluxed, are capable of making some remarkable welds. The fact that no such rod was submitted for test, in our opinion, leaves the electric welds tested at somewhat of a disadvantage and this suggests a field for further investigation.

In any discussion of welds, especially with regard to the elastic properties of a welded joint, the composite nature of the results must be borne in mind. The customary tensile specimen, taken across the weld, has certain marked advantages as an indicator of the strength of the bond between weld and plate metal but the elastic properties observed in

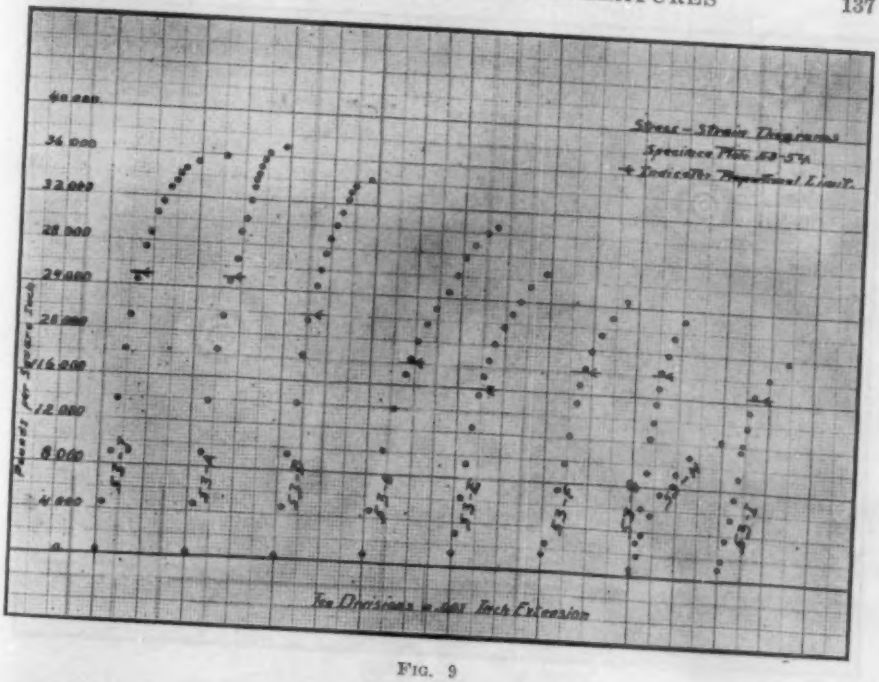
Stress - Strain Diagrams
Specimens Plate S3-S4
Indicates Proportional Limit
Pounds per Square Inch
Ten Divisions = .001 Inch Extension

FIG. 9

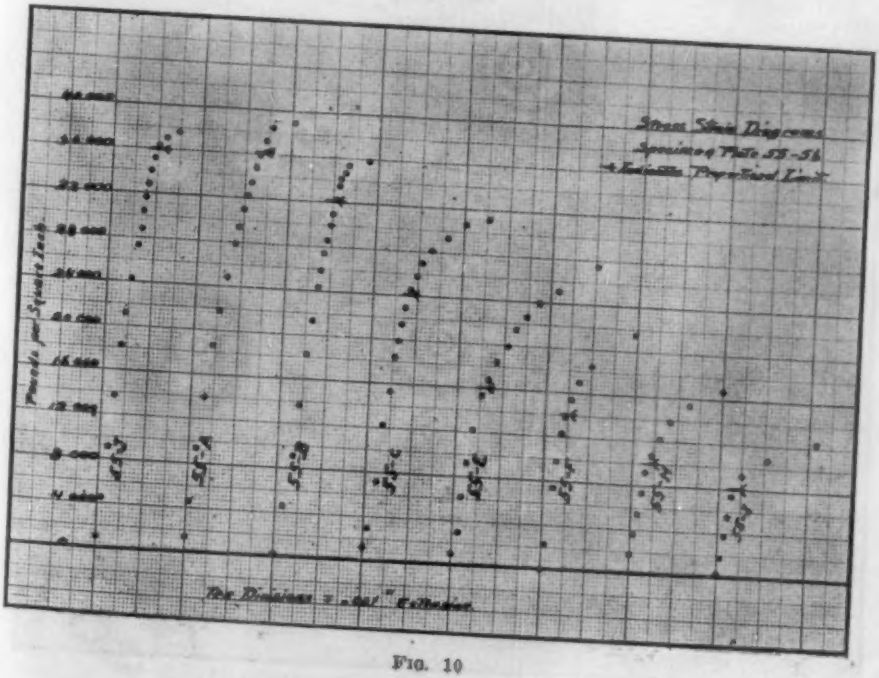
Stress Strain Diagrams
Specimens Plate S5-S6
Indicates Proportional Limit
Pounds per Square Inch

FIG. 10

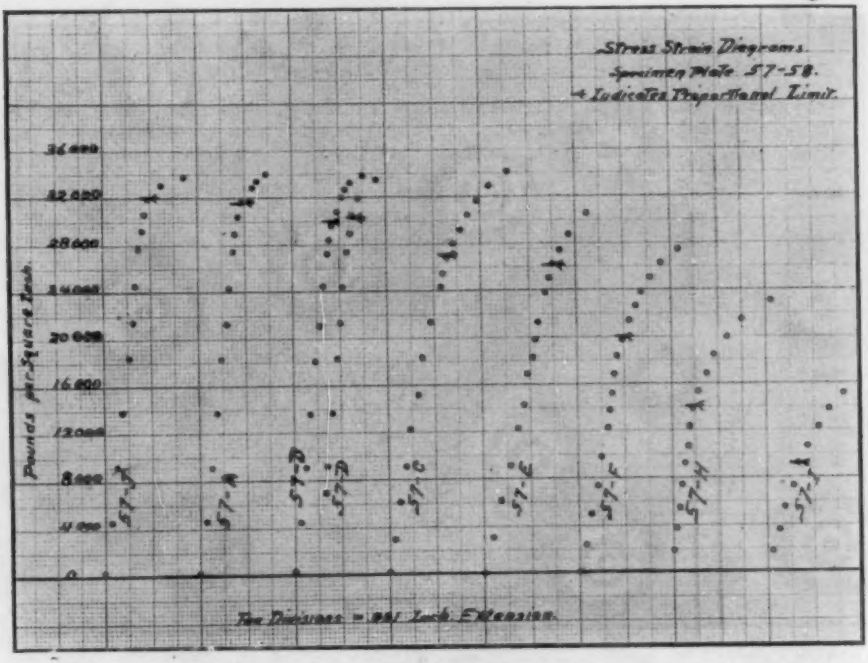
Stress Strain Diagrams.
Specimen Plate 57-58.
+ Indicates Proportional Limit.
Pounds per Square Inch.
36 000
32 000
28 000
24 000
20 000
16 000
12 000
8 000
4 000
0
57-A
57-B
57-C
57-D
57-E
57-F
57-G
57-H
57-J
Ten Divisions = .001 Inch Extension.

FIG. 11

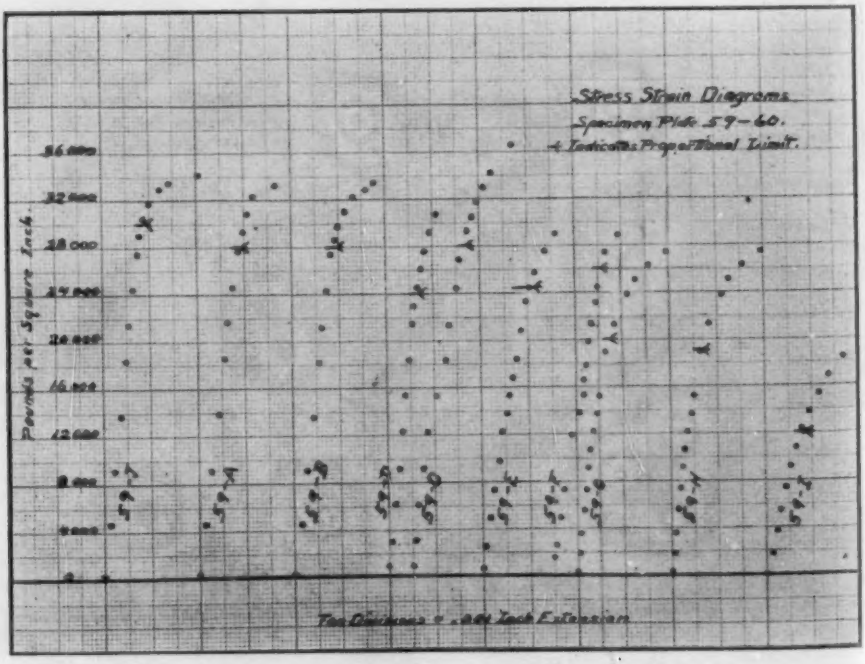
Stress Strain Diagrams.
Specimen Plate 59-60.
+ Indicates Proportional Limit.
Pounds per Square Inch.
36 000
32 000
28 000
24 000
20 000
16 000
12 000
8 000
4 000
0
59-A
59-B
59-C
59-D
59-E
59-F
59-G
59-H
59-J
Ten Divisions = .001 Inch Extension.

FIG. 12

such a specimen involve the fraction of the test length occupied by the weld.

An analyses of the elastic behavior of the components of the welded joint on the basis of knowledge of the original plate metal will be dis-

Table I

PHYSICAL PROPERTIES OF WELDS AT ELEVATED TEMPERATURES

See Figs. 13 and 14.

Specimen Number	Temperature of Test, Deg. F.	Prop. Limit, Lb./Sq. In.	Ultimate Strength, Lb./Sq. In.	Elongation, Per Cent in 2 In.	Reduction of Area, Per Cent
Rod No. 1					
53-J	78	25,000	68,700	*	†
53-A	78	25,000	68,650	26.00	38.00
53-B	296	22,000	70,000	*	†
53-C	438	18,000	74,650	*	†
53-D	Not tested	.....	.....	..	..
53-E	590	16,000	73,850	*	†
53-F	705	18,000	66,400	*	†
53-G	822	18,000	55,400	*	†
53-H	872	.....	48,000	*	†
53-I	957	16,400	41,400	*	†
Rod No. 13					
55-J	78	36,000	57,200	20.0	42.2
55-A	78	36,000	53,600	15.5	31.0
55-B	304	32,000	69,600	15.0	19.7
55-C	442	24,000	73,500	*	†
55-D	Not tested	.....	.....	...	...
55-E	560	16,000	69,600	‡10.0	9.35
55-F	742	14,000	48,300	26.0	65.5
55-G	Not tested	.....	.....	..	..
55-H	846	10,000	33,400	24.0	75.0
55-I	1,000	8,000	24,000	27.5	82.5
Rod No. 11					
57-J	72	32,000	54,300	5.0	2.5
57-A	72	31,600	58,100	6.0	5.8
57-B	305	30,000	54,600	4.0	3.7
57-C	440	27,000	62,500	2.0	3.2
57-D	303	30,400	54,300	5.0	3.65
57-E	585	26,000	68,100	5.0	6.4
57-F	712	20,000	57,900	7.5	14.6
57-G	Not tested	.....	.....	..	..
57-H	900	14,000	36,400	13.0	44.9
57-I	980	9,000	29,450	10.0	13.7
Rod No. 21					
59-J	74	30,000	64,100	6.0	4.7
59-A	73	28,000	62,900	5.0	1.5
59-B	304	28,000	67,150	6.0	7.9
59-C	440	28,000	(62,500)	2.5	2.0
59-D	444	24,000	68,900	4.0	2.8
59-E	575	24,400	74,800	*	†
59-F	756	26,000	55,800	13.5	2.9
59-G	740	20,000	59,600	12.0	18.4
59-H	838	19,000	47,500	15.0	33.5
59-I	967	12,000	31,000	7.5	2.9

* Elongation partially outside test length.
† Reduction of area took place outside weld.
‡ Failure of bond between weld and plate metal.

FIG. 12

counted owing to possible change in the plate metal adjacent to the weld. An extreme case of this would be certain of the alloys subject to air hardening adjacent to the weld, where the original plate properties may be entirely changed.

In each of those cases where the specimen broke outside the weld, the properties of the weld itself remain, in part, undetermined, the result being the overall properties of the joint. The short lengths to which reduction of section was restricted in these cases has a bearing upon the results. Note Fig. 5. Specimen No. 53-B-531 for example. The increased ultimate strengths indicate that welds are being produced considerably stronger than the plate metal, both in their body and in their bond to the plate metal. This applies over the whole practical temperature range. As to HOW MUCH stronger, this type of specimen fails to show.

It is, therefore, suggested that future work along this line be laid out in such a manner to obtain definite values for the individual properties of the weld metal and the adjacent plate. It is believed that this can be done in a manner satisfactory for the general knowledge required by the proper choice of proportions of the welded joint and method of cutting the specimens. The advantages of both types of specimen may be obtained by alternate groups of transverse and longitudinal specimens.

These tests have been carried on upon hand welded plates, Figs. 3 and 4, in which some personal equation has undoubtedly entered. It will be

PHYSICAL PROPERTIES OF PLATE METAL AT ELEVATED TEMPERATURES

See Figs. 13 and 14

Specimen Number	Temperature of Test, Deg. F.	Prop. Limit, Lb./Sq. In.	Ultimate Strength, Lb./Sq. In.	Elongation, Per Cent in 2 In.	Reduction of Area, Per Cent
1-A	75	31,000	68,250	37.5	51.5
1-J	61	21,000	67,850	40.6	51.4
2-A	75	27,200	66,600	42.2	57.0
2-J	75	29,500	66,500	40.0	51.9
1-B	358	29,000	69,500	*	†
2-B	353	29,500	71,400	*	†
2-G	446	24,000	72,500	20.0	38.6
1-C	536	18,000	74,250	26.0	33.9
2-C	529	18,500	73,250	*	†
1-E	634	15,100	69,500	34.0	47.1
2-E	628	16,500	68,650	32.5	46.1
1-F	745	10,600	61,100	38.5	58.9
2-F	763	10,700	58,200	38.5	62.2
1-H	866	13,000	46,500	36.0	62.3
2-H	873	13,600	47,150	38.0	61.0
1-I	953	10,000	37,900	39.0	63.6
2-I	966	9,500	37,000	40.0	64.6

*Elongation partially outside test length.
†Reduction of area through punch mark at one end of test length.

† Reduction of area took place outside weld.
‡ Failure of bond between weld and plate metal.

interesting to see, should the opportunity offer, what comparative results can be shown by specimens made under the practice of some of the large manufacturing firms of the country who operate automatic machines.

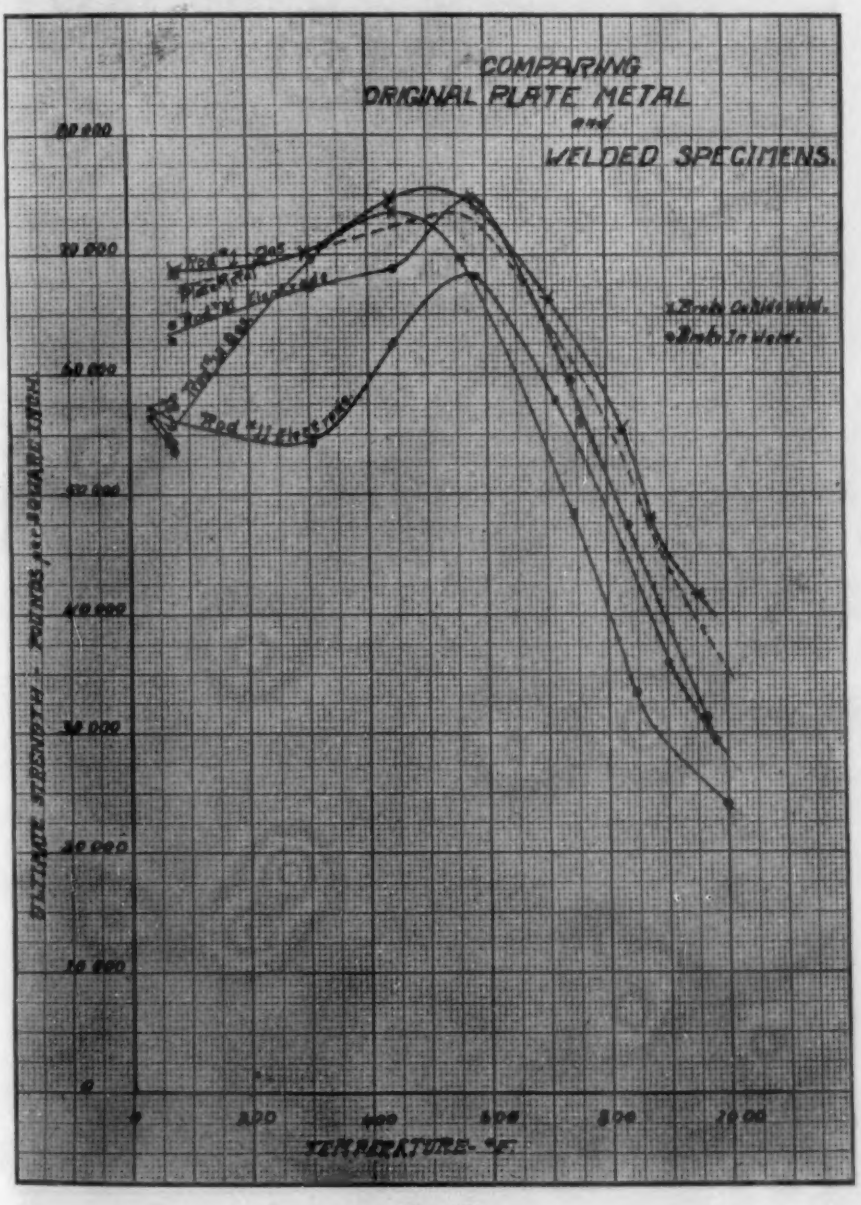

FIG. 13

*Elongation partially outside test length.
†Reduction of area through punch mark at one end of test length.

Certain of the rods can undoubtedly be tested to advantage with higher strength plate metal. The question of adaptability of a welding

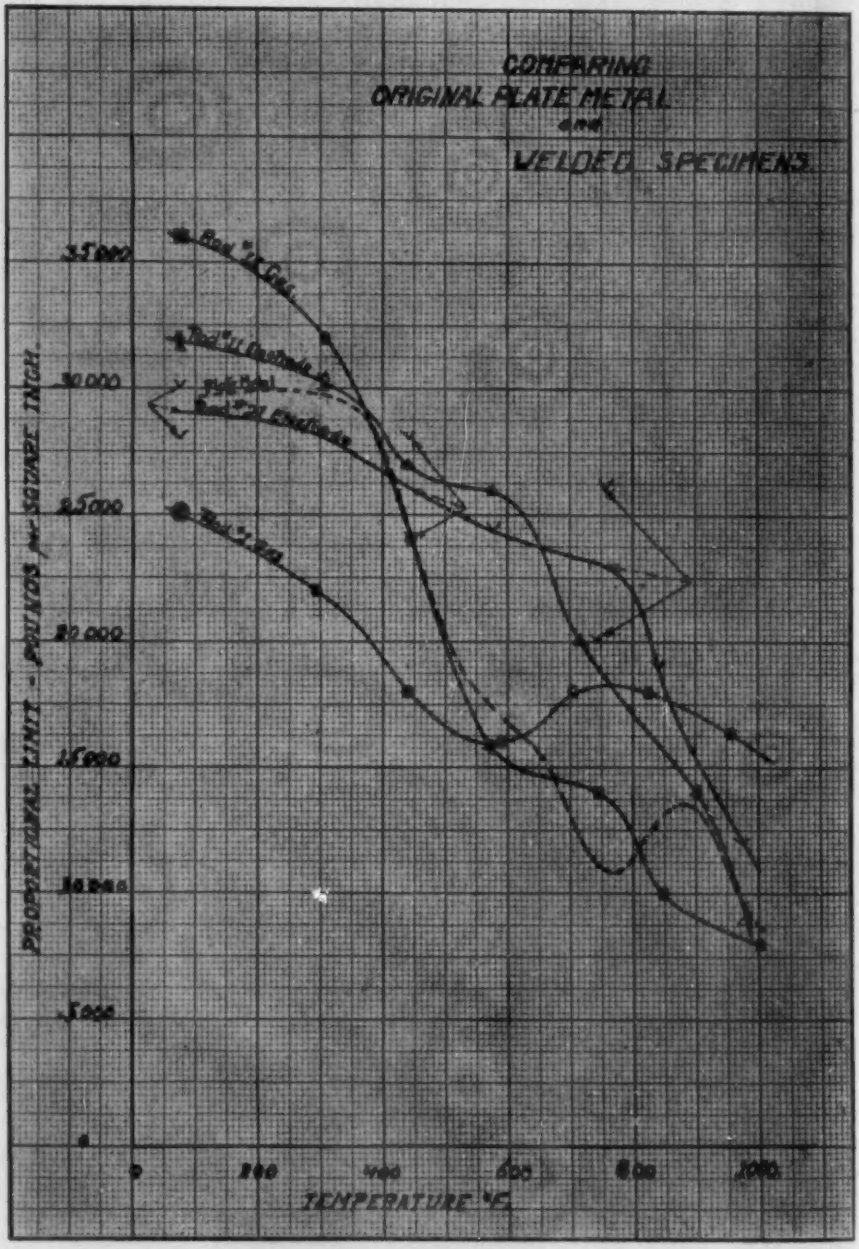

FIG. 14

FIG. 13

rod is beyond the scope of our work but where a particularly good rod is not adaptable for certain purposes research may profitably follow two courses; one, the development of technique to suit the occasion, or the other, to determine the best substitute which can be adapted. A case giving rise to such circumstances may develop under various conditions, for instance, a good rod of special strength of other desirable properties may not be found suitable for overhead welding.

While duplicate specimens are desirable the checks which have been made of points appearing questionable seem to give a degree of uniformity approaching that of the plate metal itself.

The effects of recurrent stress on welds, fatigue limit, creapage, etc., at various temperatures, all offer interesting possibilities for future investigation.

In closing it is hoped that various organizations with special facilities for preparing specimen material will continue to assist the Society and that the means can thus be provided for extending and increasing the value of the work in this field of research.

CHARLES MOSER, K. V. LAIRD

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Torchweld Equipment cuts labor and gas costs, also upkeep expense.

This same safety and dependable service are available to you.

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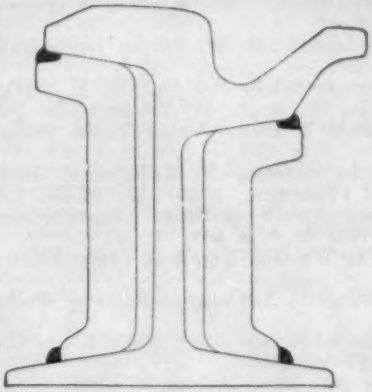

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A simple little generator* with a fine record of performance

YEARS of service have proved the value of the Carbic Acetylene Generator for welding and cutting You'll find enthusiastic users in every branch of industry. Thousands of these truly portable generators are in operation all over the country.

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For Oxy-Acetylene Welding and Cutting

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"Here, Lad—

I'm for arc welding, all right, but what puzzles me is how to apply it.

I think we ought to look a little before we leap."

Only "Stable-Arc" Welders have all these features

Variable Voltage.
Laminated Magnetic Circuit.
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Steady Arc Throughout Entire Welding Range.
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Full Capacity for either Metallic or Carbon Arc Welding.

These features make welding easier. Results — better welds and greater output.

Ask any Operator!

"Yes, Pop—

but if you look only a little, you're apt to learn only a little.

You're apt to get into the company of some of your old buddies in the non-specialty electrical business—and they'll sell you arc welding all right.

—but it will be from the viewpoint of the *jack-of-all-trades.*

Welding like insulin, salvarsan, vaccine, etc., was not developed by the general practitioner, but by the specialist, and the application is the specialist's job—but, more important, the machine itself is where you must look long and steadfast. As in all scientific development, that is where the specialist puts in the finesse that the non-specialist doesn't even understand.

And if you look first into the machine you won't have to leap—you just slide peacefully into the best welding practice.

Arc welding isn't a whole lot different from matrimony:

A wonderful state with a *helpmeet* (a good welding machine)—but Oh! what a state with a stalemate."

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"Stable-Arc" LINCOLN WELDER

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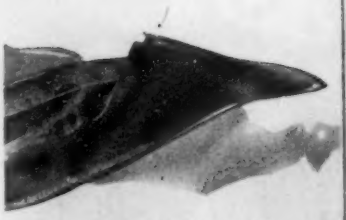

The plow, showing the break before welding

Successfully repaired with Tobin Bronze

97

There is a suitable Anaconda Filler Rod for every welding purpose. The principal Anaconda Welding Rods, with their melting points, are listed below:

for oxy-acetylene welding

Tobin Bronze	1625°F
Manganese Bronze	1598°F
Brazing Metal	1634°F
Deoxidized Copper	1981°F
Electrolytic Copper	1981°F
A. B. Naval	1625°F
Everdur	1866°F
Ambrac	2102°F

for arc welding

Phosphor Bronze	1922°F
Everdur	1866°F
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Repair-welding of chilled steel made possible with

TOBIN BRONZE

(Reg. U. S. Pat. Off.)

There are few implements which have to stand greater strain and abuse than the lowly plow. The one illustrated had a piece of metal broken from its chilled steel nose. It was successfully repair-welded with Tobin Bronze by the oxy-acetylene process.

This unusual welding job was possible only because of the low melting point of Tobin Bronze and the fact that preheating was not necessary. If steel filler rods had been used the intense heat required would have developed further cracks in the plow.

Tobin Bronze melts at 1625°F and flows freely at 1650°F. Except in the case of large jobs preheating is not necessary, thus minimizing warping, distortion and danger of cracking. In many cases Tobin Bronze Welds can be made without dismantling the piece to be welded. All this saves welding time and expense, with corresponding increase in profits.

Tobin Bronze Welding Rods are made exclusively by The American Brass Company and the trade marked name is stamped in the metal. Leading distributors of welding equipment and supplies carry Tobin Bronze.

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ANACONDA
WELDING RODS

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Mention the "Journal of the American Welding Society."

"Who is *that* man?"

"He seems to be mighty interested in that blue-print. What's he got to do with it?" asked the plant manager.

"Why, that design is his suggestion," replied the chief engineer. "He's the Linde Service Engineer. We called him in because we felt our production costs could be reduced. He's designed a set of welding jigs that will increase the hourly output of each welder. You can see what that's going to do to our costs."

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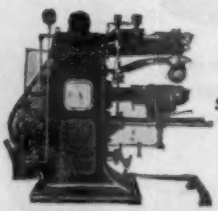

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Fourth—Installation Engineers of experience with welding machines and their application to production.

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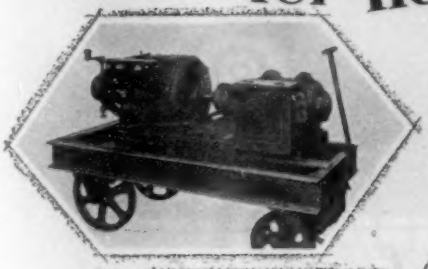

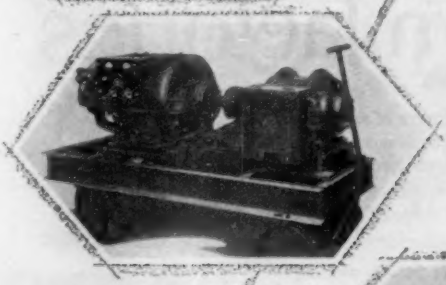

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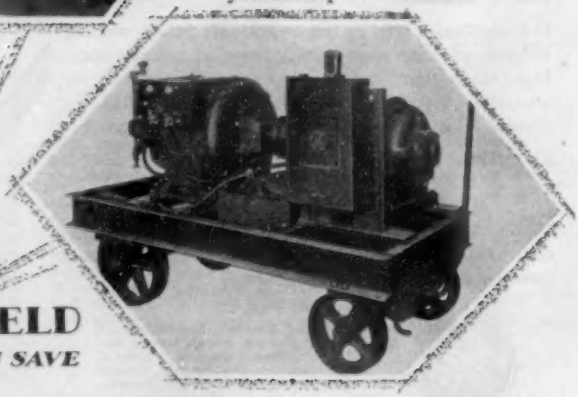
Your operators will like them because they have loads of pep for fast, high-grade welding. Because they hold the arc with remarkable steadiness. Because they permit an infinite number of current gradations by the simple turning of a handle.

You'll like them because they are the most substantial sets built. Because they are simple—no exciters or rheostats to require maintenance. Because they meet the standards of the National Electrical Manufacturers Association.

Ask your nearest G-E office to send you descriptive literature.



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GENERAL ELECTRIC

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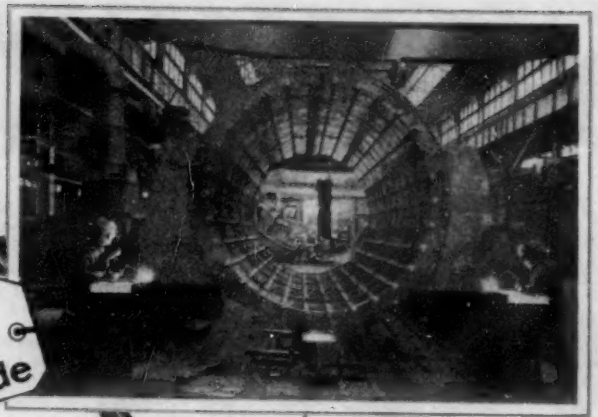

Welding the stator frame of a large generator in the Schenectady works

G-E Welding Electrode

in our own factories

General Electric is one of the largest users of arc welding in the world. G-E electrodes are employed in the construction of steel bases for large electric equipment, generator frames, transformer tanks, refrigerator icing units, etc., and in the construction of some of its new factory buildings.

G-E electrodes play an important part in arc welding because of their arc stability, ease of manipulation, rapid deposition, and good penetration resulting in sound, tough welds. These essential characteristics are present in each of the three G-E welding electrodes:

Type "F" for the general welding of steel.
Type "B" for automatic welding.
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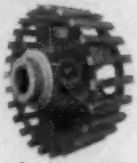
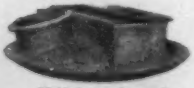
We can offer no stronger proof of our confidence in G-E welding electrodes than by using them in our own factories to build our own products.



An armature spider fabricated by welding



Welded top frame for an oil circuit breaker

G-E Welding Electrode Distributors are equipped to give you prompt service. Get in touch with the one near you or write to the Merchandise Department, General Electric Company, Bridgeport, Connecticut.

550-209D

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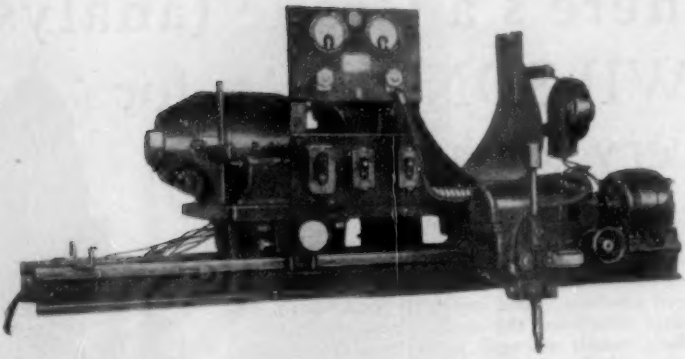
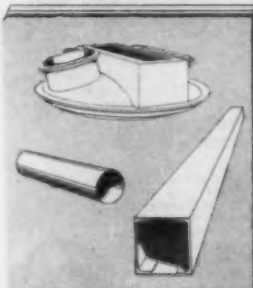
MERCHANDISE DEPARTMENT, BRIDGEPORT, CONNECTICUT



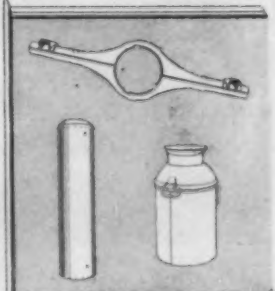
G-E AUTOMATIC ARC WELDERS

Industry's NEW *Production Tool*



Boilers, tanks, and pipes, building columns and roof trusses, ice-cream and milk cans, metal railroad ties, rear axle housings, and hundreds of other metal products with straight or circular seams are being fabricated with G-E automatic arc welders.

General Electric developed the first automatic arc welder, made the first successful application of it, and is, to-day, the world's largest manufacturer of this type of equipment. Ask your nearest G-E office for descriptive literature, advice, and assistance.



THE MORE YOU ARC WELD THE MORE YOU SAVE

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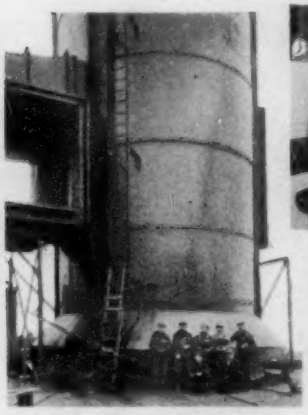
GENERAL ELECTRIC

GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y., SALES OFFICES IN PRINCIPAL CITIES

There's a Grade (analysis) of WILSON WIRE for *every arc-welding job*

SUCCESSFUL arc-welding demands the RIGHT wire for the *particular* metal which is to be welded. For instance, steel requires one analysis of wire; machineable welds on cast-iron another; and bronze, still another. And again, the purpose of the weld further determines the analysis required. Boiler work, where tensile strength is the vital factor, requires one analysis of wire; rail heads, where hardness is of first importance, require another analysis.

Wilson has developed a correct Grade (analysis) of wire for practically every welding purpose—each designated by a color, hence *"Color-tipt."* And every Grade of Wilson Wire is *uniform throughout.*



Above: Cracked locomotive cylinder Welded with Wilson Cradle No. 12 (patented U. S. A., April 6, 1920; August 30, 1921).

Above: Showing the Ohio Bell Telephone Building, Cleveland, and welder at work on one of the 16-inch Steam Risers that feed fifteen stories of the building. After exhaustive laboratory tests, Wilson Wire was chosen for every weld on this job. Wilson Grade No. 6 (patented U.S.A., June 13, 1916; March 9, 1920; Canada, March 19, 1918) and Wilson Grade No. 9 (patented U.S.A., June 13, 1916; March 9, 1920) were used.

At left: One of several stacks at the Edison Plant, 14th Street and East River, New York, on which Wilson Grade No. 17 (patented U. S. A., June 13, 1916; March 9, 1920) was used. All seams were welded on the inside to forestall corrosion from acid deposits. Each stack is 256 feet high and 22½ feet in diameter, and contains 8000 feet (1½ miles) of arc-welding.

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Because it is of Uniform Size—Free from Dust—works perfectly in all makes of Carbide Lamps and Generators—gives most gas per pound, and is made of the very finest materials in the most modern plants.

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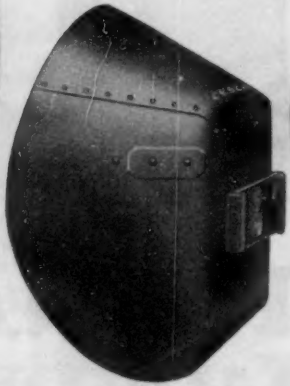
For Electric Arc and Acetylene Welders

HANDSHIELD
MODEL "O"—PRICE $5.00



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CESCO Model "O" Handshield and "OO" Helmet have been designed to include extreme lightness of weight, proper ventilation and the absolute exclusion of all outside light. Both Models carry the usual CESCO indorsement, and are fitted with genuine ESSENTIALITE Lenses.

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TITAN-Light Goggles

TITAN-Light goggles afford the wearer a new degree of comfort and safety. They are made of a new light weight, moisture proof material, which is durable, heat resisting, non-inflammable and easily sterilized.

The cups are shaped to fit the contour of the face and special indirect ventilation slots permit proper circulation without allowing sparks or light to enter.

Price, Complete with ESSENTIALITE Lenses, $2.25 Pr.

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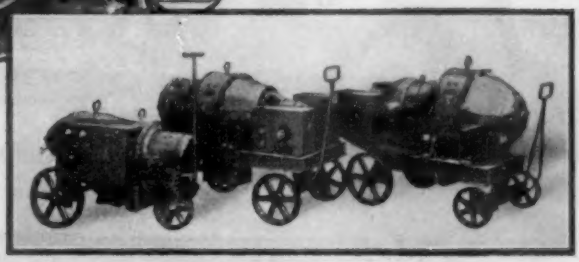

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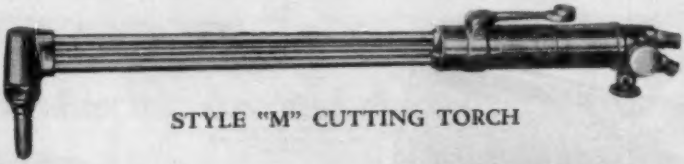

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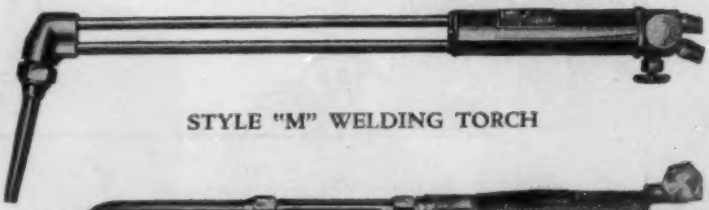

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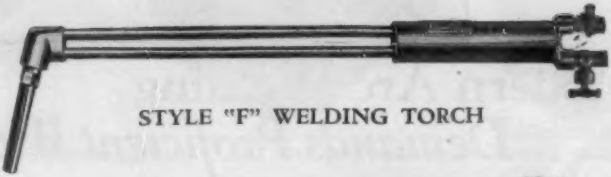

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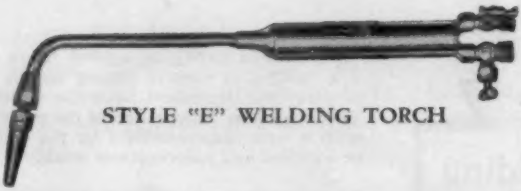

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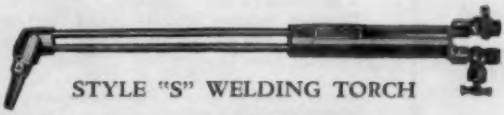

STYLE "S" WELDING TORCH

STYLE "L" WELDING TORCH

A Few Styles and Sizes of Torches

Manufactured by

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New 1929 Model!
FUZON ARC WELDER

A truly Portable Unit –

GAS ENGINE DRIVEN

No matter where the job is, this welder can be taken to it! New principles of design are incorporated, eliminating induction coils, reactors and other troublesome adjuncts. Has but one single control, giving an infinite number of current gradations. Extremely easy to operate.

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SKILL AND GOOD TOOLS MEET.

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Special features which have caused the Milburn Regulator to be standardized by leading users of cutting and welding equipment the world over: 1. Solid bronze forging—bridge-like construction. Cannot crush in. 2. Permanent non-stripping threads. 3. Parts telescopic, giving perfectly aligned seat. 4. Seat the most easily accessible of any regulator made. Seats WITH instead of AGAINST the pressure. 5. Diaphragm movement, limited by patented abutment, cannot be strained or inverted. 6. Fewer parts than other regulators and all parts easily "get-at-able." 7. Will not stick or freeze. 8. Many regulators fail to keep up the desired volume and pressure as the high initial pressure diminishes. This affects cutting and welding efficiency and economy. The Milburn Regulator overcomes this fault. In spite of diminishing initial pressure, the Milburn will keep up or increase the delivery pressure.

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Supplied in the following size cylinders:

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Strong welds are made only when the best electrodes are used. Roebling Welding Wire is manufactured to meet the most rigid specifications. It is uniform throughout each shipment and all shipments. Look for the JR trade mark on each electrode.

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Thermit Welding has solved the problem of heavy repairs in many large industrial plants. Thermit welds together the broken parts or builds up worn parts, making a homogeneous mass of metal. Drastic improvements in the methods of Thermit Welding have materially reduced the cost so that it can now be done more quickly and economically than other methods of welding.

Special Thermit steels can be furnished for practically any analysis and Thermit is being found very satisfactory for many production jobs where welding of heavy sections is necessary.

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MEMBERSHIP APPLICATION BLANK

AMERICAN WELDING SOCIETY
33 WEST THIRTY-NINTH STREET
NEW YORK, N. Y.

.....192.

Secretary:

I hereby apply for Membership in the AMERICAN WELDING SOCIETY as a ..... Member and attach
(Note Grades on other side)
hereto remittance of $..... for first annual dues. Remittance will be refunded in the event of rejection of applicant. I also agree to abide by the Constitution and By-Laws of the Society.

Name .....

Present occupation .....

Name of Company and Address .....

Residence .....

Address for mailing .....

Applicant is requested to state here length of welding experience and processes involved, also to record any technical or mechanical experience or special interest in the welding field.

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References: (1. .....

(at least two) (2. .....

Proposed by .....

(See other side)

CUT OFF ALONG THIS LINE

QUALIFICATIONS FOR MEMBERSHIP

Extract from By-Laws

ARTICLE I.

Section 1. Individuals having received the approval of a majority of the Membership Committee shall become members of this Society upon the payment of dues, except in the cases of honorary members who shall be elected by unanimous vote of the full Board of Directors.

Section 2. Membership shall be divided into five classes:

Sustaining Members, being individuals or individuals delegated by corporations, firms, partnerships, etc., interested in the science and art of welding, with full rights of membership.

Annual dues..... ..... $100.00

Members, being individuals interested in the science and art of welding, with full rights of membership. Engineers or individuals competent by experience or training to plan or direct welding operations are eligible to this class.

Annual dues..... $20.00

Associate Members with right to vote but not to hold office, except in Sections as may be provided for by the By-Laws of the Section. Supervising welders, inspectors and skilled operators, with three or more years' practical experience in welding, are also eligible to this class.

Annual dues..... $10.00

Operating Members, who are welders or cutters by occupation, without the right to vote or hold office except in Sections as may be provided for by the By-Laws of the Sections.

Annual dues, United States and Canada $5.00
Other countries..... $10.00

Student Members, who are actually in attendance at any one of the recognized colleges and approved trade schools, without the right to vote or to hold office except in Sections as may be provided for by the By-Laws of the Section.

Annual dues..... $2.50

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The improvement made possible by better welding is brought out by this exhaust manifold. It is typical of the many advantages resulting from modern welding construction.

Good welding affords a higher efficiency than is possible with mechanical types of fittings. There are fewer places where trouble might occur —less upkeep required—the job is more dependable.

PAGE Welding Wire was used in the manufacture of this exhaust main because it assures uniform welds at the lowest possible cost. Welders prefer this better product because it saves labor, money and time, and enables them to do better work.

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Make your own convincing test of PAGE Welding Wire and Electrodes. Your name and address bring a free sample—investigate today.

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